

REVIEW

Technological and artificial intelligence pathways to psychological empowerment and health in basketball: A narrative review on virtual reality, biofeedback, and mindfulness

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Abstract

Background: Modern basketball demands attentional control, rapid decision-making, and regulation of anxiety under pressure. Virtual reality (VR), biofeedback or neurofeedback, and mindfulness-based training are increasingly used, yet their combined contribution to psychological empowerment and mental health remains unclear.

Objective: This narrative review synthesized evidence from 2015 to 2025 using Scopus, PubMed, and Web of Science, supplemented by reference chaining, and integrated findings through a predefined mechanism framework and a qualitative evidence-weight appraisal. VR studies in basketball and closely related sports suggest improvements in perceptual-cognitive decision skills and provide standardized pressure exposure; however, most evidence is short-term and relies on near-transfer outcomes with limited competition-level validation. Heart rate variability biofeedback shows more consistent support for arousal regulation and pressure-sensitive performance stability, whereas electroencephalography neurofeedback remains promising but heterogeneous, with few basketball-specific trials. Mindfulness-based programs can strengthen attentional stability, acceptance, and rapid refocusing, with mixed findings for broader mental health outcomes and clear dose- and context-dependent boundary conditions. A complementary model is proposed in which VR provides representative exposure and rehearsal, biofeedback supports physiological self-regulation, and mindfulness supports cognitive-emotional regulation. Current artificial intelligence use is best characterized as decision support, for example, readiness analytics from heart rate variability, sleep, and wellness reports, adaptive training difficulty, and trend dashboards, while predictive real-time multimodal systems remain largely prospective and require validation.

Conclusion: Future research should prioritize basketball-specific controlled trials, ecologically valid outcomes, and longitudinal designs that test underlying mechanisms and durable transfer.

Keywords: Basketball; Psychological empowerment; Virtual reality; Biofeedback; Mindfulness; Artificial intelligence

1. Introduction

Psychological empowerment and mental health are increasingly recognized as vital components of elite basketball performance.¹ In high-stakes games, players must regulate anxiety, maintain attentional focus, make split-second decisions, and demonstrate resilience in the face of setbacks. The ability to enter a state of flow and execute skills confidently under pressure often separates top performers. Conversely, excessive stress or lapses in concentration can impair decision quality and motor execution, sometimes leading to “choking” in critical moments. As such, modern training paradigms in basketball are expanding beyond physical and technical preparation to deliberately cultivate mental skills and emotional well-being.² In this narrative review, we treat psychological empowerment as a performance-relevant capacity grounded in perceived control and effectiveness in self-regulation, encompassing confidence under pressure, attentional control, adaptive stress responding, and resilient recovery after errors. This framing allows a direct link between empowerment, performance stability, and athlete well-being, while also enabling critical evaluation of interventions that claim to improve the mental game but may operationalize outcomes inconsistently.

Alongside this shift, there is growing recognition that these psychological processes unfold within an increasingly digital performance ecology.³ Cyberpsychology, commonly defined as the study of human mental processes and behavior in the context of human–technology interaction, encompasses how digital tools, platforms, and virtual environments shape cognition, emotion, identity, and social relationships.⁴ Within this broader field, sport and health cyberpsychology focuses specifically on how technologies such as virtual reality (VR), wearable sensors, online platforms, and social media influence athletes’ performance, well-being, and help-seeking behaviors, as well as the way sport psychologists deliver their services.⁵ This narrative review highlights that technological innovations in basketball are not merely neutral tools but interventions that interact with athletes’ attentional styles, motivational climates, and social environments, potentially enhancing psychological empowerment or introducing new cyber-related stressors.⁶ Accordingly, any evaluation of technology-enabled mental training should address both benefit pathways, for example, improved rehearsal, feedback, and engagement, and risk pathways, for example, cognitive overload, surveillance-like monitoring, and

autonomy-undermining practices that may erode trust and well-being.

Emerging technologies provide novel pathways to train these psychological aspects. VR has matured from bulky lab setups to portable head-mounted displays, enabling immersive simulations of game scenarios.⁷ VR’s appeal lies in its capacity to recreate realistic basketball environments, including crowd noise, opposing defenders, and time pressure, within a controlled setting. This allows athletes to practice cognitive–perceptual skills, such as scanning for open teammates or anticipating opponents’ moves, and experiencing high-pressure situations without real-world consequences.⁸ Research in invasion sports suggests that VR training can improve decision-making that transfers to real games.⁹ For example, Pagé *et al.*¹⁰ showed that basketball players who underwent VR decision-training not only performed better on trained in-game scenarios but also showed generalized improvements in novel plays. Moreover, by increasing immersion and engagement, VR training may invoke the intense focus and situational awareness needed in real competitions. Reviews such as that of Richlan *et al.*¹¹ note that VR-based interventions often outperform passive video or conventional drills in boosting sport-specific motor and mental skills, including strategic decision-making and responding to unexpected events. With the wider availability of affordable VR equipment, basketball teams are now more inclined than ever to integrate VR drills for mental conditioning. At the same time, VR literature remains uneven in ecological validity. Transfer to in-game behavior is not consistently tested, protocols vary in fidelity and interactivity, and practical barriers such as cybersickness and training time constraints shape real-world feasibility. These limitations matter theoretically because empowerment is not only about skill acquisition, but also perceived control under realistic stress conditions, which requires evidence that learning generalizes beyond the simulated task.

Wearable sensors and biofeedback devices have likewise become more accessible, creating opportunities for training athletes’ self-regulation skills.¹² Heart rate monitors, portable electroencephalography (EEG) headsets, and other wearables can provide real-time physiological data, for example, heart rate variability (HRV) and brainwave activity. HRV biofeedback training, which typically teaches individuals to control breathing to optimize heart rate variability, has shown evidence of enhancing parasympathetic (vagal) activity and improving

stress recovery in athletes.^{13,14} A systematic review by Jiménez Morgan and Molina¹⁵ found that in ~86% of included studies, HRV biofeedback led to improvements in psychophysiological variables and sport performance, despite generally small sample sizes. In basketball, where clutch performance, for instance, a free throw in the final seconds may hinge on calming one's nerves, the ability to consciously down-regulate arousal is invaluable. HRV biofeedback trains this skill by giving athletes immediate feedback on their internal state and rewarding effective breathing control with improved coherence metrics. Similarly, EEG neurofeedback allows athletes to learn to produce brain activity patterns associated with focus or "in the zone" performance. Although evidence for EEG neurofeedback in sport is still emerging, a recent meta-analysis reported a moderate positive effect of neurofeedback training on athletes' motor performance tasks, suggesting that learning to self-modulate brain states can translate into tangible performance gains.¹⁶ Overall, biofeedback modalities align with the self-regulation aspects of psychological empowerment, giving athletes a greater sense of control over anxiety, attention, and physiological stress responses.¹⁷ However, biofeedback literature also raises methodological and conceptual questions relevant to empowerment and health. Device validity and outcome heterogeneity complicate synthesis, and intensive monitoring can shift the motivational climate toward external control if data are used punitively or without transparent consent. A cyberpsychology-informed approach, therefore, requires that biofeedback be framed as autonomy-supportive skill development rather than surveillance.^{18,19}

In parallel with technology-driven tools, there has been a rise in the use of mindfulness and meditation practices in sports.²⁰ Mindfulness, typically defined as non-judgmental present-moment awareness, targets cognitive-affective skills such as attentional control, emotion regulation, and acceptance of uncontrollable events.²¹ These skills directly support athlete health, for example, by mitigating chronic stress and burnout risk²² and performance by preventing distractions and ruminations from derailing play.^{23,24} Indeed, mindfulness-based interventions (MBIs) have shown efficacy in a variety of sports settings. A 2024 meta-analysis by Si and colleagues found that mindfulness interventions significantly improved athletes' mindfulness levels and certain performance-related psychological factors (aggregate standardized mean difference ~0.5–0.8),²⁵ although their direct impact on objective performance outcomes was often reported only in narrative or indirect terms.²⁶ In basketball-specific research, studies have observed that players high in dispositional mindfulness and who maintained consistent pre-shot routines had

higher free-throw percentages, whereas those with higher baseline anxiety (arousal) showed worse performance under pressure. This suggests that mindfulness may buffer against performance-sapping anxiety and promote routine behaviors that stabilize execution.² Arthur-Cameselle and Keeler²⁷ demonstrated that a brief 15-minute mindfulness session could improve collegiate players' free-throw shooting in a high-pressure scenario compared to controls. Mindfulness practice cultivates an athlete's ability to stay grounded in the present moment, to accept negative thoughts or mistakes without catastrophizing, and to quickly refocus, capacities that contribute to a sense of empowerment and resilience.²⁸ Additionally, mindfulness training offers broader health benefits for athletes, including reduced cortisol levels and improved mood regulation, which can help protect against overtraining or mental burnout.²⁹ Critically, evidence on mindfulness also underscores the importance of dosage, implementation context, and athlete readiness. Null or mixed findings in brief interventions suggest that theoretical mechanisms, such as decentering and acceptance, may require sustained practice to reliably influence performance and well-being. This variability reinforces the need for integrative frameworks that specify when, for whom, and through which mechanisms mindfulness supports empowerment in competitive basketball.³⁰

From a cyberpsychological standpoint, the integration of VR, wearables, and app-based mindfulness also raises questions about digital overload, datafication of the athlete, and potential problematic or compulsive technology use. Cyberpsychology research on social media, gaming, and online platforms has documented both benefits, such as increased connectedness and access to support, and risks, such as overuse, distraction, and behavioral addictions. Applied to basketball, this means that the same technologies that offer powerful training environments can, if poorly managed, contribute to information overload, performance pressure amplified by online scrutiny, or surveillance-like monitoring that undermines athletes' autonomy and trust. A sport cyberpsychology lens, therefore, encourages practitioners to design interventions that leverage digital tools to enhance control, competence, and relatedness, while monitoring cyber-related stressors and ensuring ethical use of data.³¹

Taken together, prior research suggests promise but also reveals three interrelated gaps that limit scholarly and practical advancement. First, the evidence remains siloed, with VR, biofeedback, and mindfulness typically studied separately, which prevents a coherent account of how these tools might complement one another in the same athlete across a season.³² Second, the literature often emphasizes

intervention effects without sustained theoretical dialogue about empowerment mechanisms, boundary conditions, or tradeoffs, for example, performance gains at the cost of autonomy undermining monitoring.³³ Third, conceptual clarity is limited by heterogeneous outcomes and inconsistent linkage between short-term task improvements and broader indicators of psychological empowerment and mental health. These gaps motivate an integrative synthesis that not only reports results but also critically evaluates mechanisms, feasibility, and ethical implications within a unifying framework.³⁴ To improve conceptual communication and respond to the need for framework development, we also introduce a visual synthesis in this paper. Specifically, we present a conceptual model that links VR, biofeedback, and mindfulness to empowerment-relevant mechanisms and outcomes, and we summarize the framework in a table that maps each modality to key mechanisms, expected performance and well-being outcomes, implementation constraints, and cyber ethical considerations. This approach aims to make the review's logic transparent and practically actionable.^{35,36}

1.1. Objective of this review

This narrative review aims to synthesize current knowledge on how VR, biofeedback, and mindfulness interventions contribute to psychological empowerment and health in basketball. The focus is on the mechanisms by which each approach influences attention, stress regulation, self-efficacy, and resilience, as well as on practical protocols applied in basketball or closely related sport tasks, including free throws, decision-making drills, and balance training. A further objective is to examine how artificial intelligence (AI) can enhance these approaches through personalization and continuous feedback, while explicitly addressing ethical considerations, including data privacy and player consent. In adopting a critical synthesis orientation, this review evaluates not only what has been reported in the literature but also how convincingly mechanisms have been tested, where evidence is constrained by design or ecological transfer, and what theoretical implications follow for psychological empowerment and athlete well-being in a digitally mediated sport environment.

We address three guiding questions:

- (i) Which psychological empowerment mechanisms and constructs, for example, self-efficacy, attentional control, arousal regulation, acceptance, and resilience, are targeted by VR, biofeedback, or neurofeedback, and mindfulness interventions in basketball, and what evidence supports these pathways?
- (ii) Which intervention protocols, including dosage, fidelity, task design, and delivery format, show efficacy for basketball-relevant performance and well-being outcomes, and what are their limits in terms of ecological transfer, feasibility, and methodological quality?
- (iii) How can AI-enabled personalization and monitoring be responsibly integrated into a coherent framework combining VR, biofeedback, and mindfulness in team sport settings, while safeguarding privacy, consent, autonomy, and minimizing digital load and unintended cyber-related stressors?

By exploring these questions, this review seeks to provide coaches, sport psychologists, and performance staff with a consolidated understanding of these innovative training pathways and offer evidence-based recommendations for their implementation in basketball. We also identify gaps in the literature and propose directions for future research to better establish long-term impacts on both performance outcomes and athlete mental health.

2. Methods

Narrative review methodology was adopted to enable an integrative synthesis across diverse study designs (experimental, quasi-experimental, qualitative) and disciplines (sport science, psychology, engineering). In contrast to systematic reviews designed for quantitative aggregation, this approach was appropriate for synthesizing mechanistic insights, contextual factors, and implementation considerations relevant to VR, biofeedback, or neurofeedback, and mindfulness in basketball. Transparency was supported through explicit reporting of the literature search strategy, eligibility criteria, screening steps, and a structured analytic framework, while no systematic review reporting workflow intended for meta-analytic aggregation was applied.

2.1. Literature search and sources

Three major databases, Scopus, PubMed, and Web of Science, were searched for publications from 2015 to 2025. This window was selected to capture the period when immersive VR and wearable biofeedback technologies became more widely accessible and when research on mindfulness in sport expanded substantially. Earlier foundational studies published before 2015 were incorporated selectively through reference chaining when they were directly relevant to the mechanisms, protocols, or implementation issues addressed in the review.

Scopus, PubMed, and Web of Science were selected because they provide complementary coverage consistent with the topic's interdisciplinary scope. Scopus offers broad indexing across sport science, psychology, health, and engineering outlets. PubMed provides strong

coverage of biomedical and health-related literature relevant to psychophysiology, stress regulation, and mental health outcomes. Web of Science provides curated multidisciplinary indexing and robust cited-reference functionality to support forward and backward citation searching. Collectively, these databases reduce the likelihood of missing relevant evidence across the three intervention pillars.

The search strategy combined keywords for each pillar with sport/basketball terms. For VR, search strings included combinations such as “virtual reality AND basketball” and broader terms like “VR training AND sport AND performance.” For biofeedback, we used terms such as “heart rate variability biofeedback AND (sport OR basketball),” “EEG neurofeedback AND athletes,” and specific modalities (“respiratory biofeedback,” “EMG biofeedback”) to ensure we captured a range of approaches. The mindfulness searches used terms such as “mindfulness intervention AND (athlete OR basketball OR sport performance),” and related concepts (“meditation,” “acceptance training,” “MAC program sport”). Given the review’s scope, we included literature in both English and Greek, since some sports science research in Greece could provide relevant data.³⁷

We also searched the reference lists of recent systematic reviews and meta-analyses for each pillar to identify key studies. Examples of such high-quality sources we leveraged include: Richlan *et al.*⁷ for VR in sports, Jiménez Morgan and Molina² for HRV biofeedback, a narrative review by Sánchez *et al.*⁸ specifically on HRV in basketball, the meta-analysis by Yu *et al.*¹⁶ and Rydzik *et al.*³⁸ on neurofeedback, Si *et al.*²⁵ for mindfulness meta-analysis, and Bühlmayr *et al.*²⁰ on mindfulness in sport. These provided structured insights and guided us to important primary studies.

2.2. Inclusion criteria

Empirical sources were eligible if they (i) involved athletes or healthy participants in sport contexts, with basketball prioritized when available, (ii) evaluated an intervention or structured application involving VR training, biofeedback or neurofeedback, or mindfulness or meditation based training, and (iii) reported outcomes related to performance, psychological variables (e.g., anxiety, confidence, attention), and/or health and well-being (e.g., stress markers, recovery indicators, burnout-related outcomes). No age restrictions were applied; studies including adolescent and adult samples were eligible. No competitive-level restrictions were applied; evidence from recreational, collegiate, elite, and adaptive sport contexts was eligible, while basketball-specific populations were prioritized, and other sports were used only when task

demands were closely transferable.

In addition to primary empirical studies, secondary syntheses (systematic reviews and meta-analyses) were eligible if they were directly relevant to at least one pillar and when they informed protocol characteristics, boundary conditions, or trustworthiness appraisal. Selected conceptual and implementation-focused sources were also eligible when they addressed monitoring validity, data governance, ethical safeguards, or implementation constraints that directly condition interpretability and real-world feasibility.

Exclusion criteria included studies that did not evaluate an intervention or structured application, studies not situated in sport or performance contexts, and sources lacking sufficient methodological detail to support appraisal. Grey literature in the form of Master’s theses and doctoral dissertations was not included.

The evidence base was restricted to English-language publications to ensure accessibility to the journal’s international readership and to maintain consistency in appraisal and reporting. Greek-language screening was initially considered to reduce language bias; however, no Greek-language peer-reviewed studies meeting the eligibility criteria were retained in the final evidence set. Consequently, no Greek-language references appear in the reference list.

The final evidence tables included 36 unique sources overall. By pillar, VR-focused sources numbered 8, biofeedback or neurofeedback sources numbered 13, mindfulness-focused sources numbered 9, and integrative or AI-related sources numbered 14. Because some sources are cross-cutting, a small number appear in more than one pillar-specific table.

2.3. Screening and data extraction

Titles and abstracts were screened independently by two reviewers after duplicate removal. Potentially eligible records were assessed in full text. Disagreements were resolved by discussion to reach a consensus. For each included source, key data were extracted into a structured extraction grid covering population and setting, intervention characteristics and protocol features, outcomes and measures, proposed or tested mechanisms, transfer indicators, and feasibility or implementation constraints. The extraction grid supported cross-study comparison and thematic integration across modalities.

2.4. Analytical framework and synthesis strategy

To strengthen transparency and reduce the subjectivity that can affect narrative reviews, we applied an explicit, a priori

analytical framework aligned with the review objective and guiding questions. This framework was grounded in our conceptualization of psychological empowerment as a self-regulation-oriented capacity within a digitally mediated performance ecology. Accordingly, we treat empowerment as emerging from identifiable psychological mechanisms and constructs that plausibly link exposure to interventions to performance and well-being outcomes, including self-efficacy, attentional control, arousal regulation, cognitive appraisal under pressure, psychological flexibility and acceptance, and resilience following setbacks. In parallel, we used a sport cyberpsychology lens to ensure that technology-enabled interventions were evaluated through both benefit pathways, for example, improved rehearsal, feedback, and engagement, and risk pathways, for example, digital load, monitoring burden, autonomy erosion, and trust-related concerns, with explicit attention to data governance and consent.

Using this framework, each included source was coded in an extraction matrix that captured five domains. First, intervention modality and protocol features, including dose, duration, fidelity, delivery format, and task demands. Second, targeted empowerment mechanisms and how these were operationalized, for example, whether self-efficacy or attentional control was measured directly, inferred from proxy outcomes, or left implicit. Third, outcomes, categorized as performance, psychological, and health-related, including the type of measure used and the extent to which outcomes were basketball relevant. Fourth, implementation constraints and ecological transfer considerations, including feasibility in team contexts, adherence, cybersickness where relevant, and evidence of transfer to in-game behavior or durable follow-up. Fifth, digital and ethical considerations, including autonomy support, privacy protections, consent procedures, and the potential psychosocial impact of intensive monitoring.

Because of the risk of uncritical citation in a heterogeneous evidence base, a structured trustworthiness appraisal was embedded in the synthesis. Numeric quality scores were not computed. Instead, each included study was assigned a qualitative evidence weight (higher, moderate, or lower) using transparent criteria, including study design and comparator quality, sample adequacy and representativeness, measurement validity and reliance on objective outcomes, analytic transparency and handling of attrition, presence of follow-up, and explicit testing of ecological transfer. For secondary sources, the appraisal considered the clarity of the inclusion criteria, transparency of search procedures, and whether limitations and potential biases were critically discussed. This trustworthiness appraisal informed interpretation in two

ways. First, convergent patterns supported by controlled designs, meta-analytic evidence, or consistent findings across multiple independent studies were prioritized. Second, when evidence was limited by small samples, weak comparators, or laboratory proxy outcomes, uncertainty was stated explicitly, causal language was avoided, and conclusions were framed as provisional.

The narrative synthesis was then conducted in two stages. Within-modality synthesis summarized evidence on VR, biofeedback, neurofeedback, and mindfulness by emphasizing mechanisms, protocol characteristics, and boundary conditions rather than listing study results. Cross-modality integration identified convergences and trade-offs among interventions, forming the basis of the conceptual model and summary table described in the Introduction. To improve readability and scholarly value, detailed study-by-study summaries were consolidated into tables or appendices, while the main text focused on integration, critique, and theoretical implications for psychological empowerment and athlete well-being.

Finally, the AI subsection was treated as an integration and implementation layer rather than a stand-alone evidence base. To maintain stylistic consistency and avoid overly idealistic claims, we distinguished between empirically supported applications, pilot or prototype evidence, and forward-looking proposals. Claims about real-time adaptation of emotional or performance states were included only when supported by data. Otherwise, they were explicitly framed as plausible directions requiring future validation, alongside concrete ethical safeguards related to privacy, consent, autonomy, and minimizing digital load and unintended cyber-related stressors.

3. Narrative synthesis

3.1. Virtual reality for pressure, perception, and decision-making

3.1.1. Task demands addressed

This subsection addresses Guiding Question (i) by specifying psychological empowerment mechanisms plausibly trained via VR, and Guiding Question (ii) by evaluating protocol features, feasibility constraints, and the current strength of evidence for transfer to basketball performance and well-being outcomes.

In basketball, critical cognitive-perceptual tasks include reading offensive and defensive patterns, making split-second decisions (pass, shoot, drive) under time pressure, maintaining spatial awareness of the court, and keeping balance and control during dynamic movements (such as contesting a rebound or making a layup while avoiding contact).^{38,39} VR-based training has been explored

in many of these areas. By creating a virtual environment, for instance, a 360° video or computer-generated court scenario, VR allows players to practice decision-making in complex game situations, train their attention to relevant cues (like a defender's body positioning), and even practice motor skills like shooting or footwork with augmented feedback. Importantly, VR can also introduce stressors such as countdown clocks, virtual crowd noise, or high-stakes narratives (e.g., "last shot of the finals") to address the psychological pressure aspect.⁴⁰

From a psychological empowerment perspective, VR most plausibly targets (a) attentional control and cue utilization, namely the ability to select task-relevant information while inhibiting distraction, (b) cognitive appraisal under pressure, including shifts in threat versus challenge interpretation of time pressure and evaluative contexts, (c) self-efficacy via repeated mastery experiences in standardized scenarios, and (d) self-regulation routines, such as brief breathing or refocusing cues practiced at the moment of decision. This mechanism framing matters because VR should not be evaluated only as a novel delivery format, but as a tool whose value depends on whether it trains perceived control and effective regulation under representative competitive constraints (Table 1).

3.1.2. Decision-making and game intelligence

Evidence for VR-based decision training in basketball is anchored by interactive video simulation work demonstrating improvements in decision quality and generalization to novel plays.³ Complementary engineering-oriented studies have developed action-aware or AI-supported VR systems aimed at improving decision making through repeated exposure to representative scenarios and feedback, with feasibility and performance signals reported in prototype implementations.^{41,42} At the review level, synthesis of VR applications in basketball indicates growing use of VR for tactical rehearsal and decision training, but also considerable heterogeneity in hardware, task design, outcome metrics, and comparators, which constrains firm conclusions about effectiveness across settings. Broader sport-level reviews similarly suggest that interactive VR can support perceptual-cognitive training, yet emphasize variability in study quality, training dose, and transfer assessment.^{7,8}

Trustworthiness and interpretive caution are essential here. Many VR decision studies use short interventions with small samples and rely on near-transfer outcomes, such as performance within the VR task itself, rather than validated in-game indicators. Comparator conditions are inconsistent, ranging from no additional training to video-based practice, limiting causal inference. Consequently,

the most defensible reading is that VR decision training is promising when it is representative and interactive, but the evidence base remains uneven, and claims of consistent real-game improvement should be proportional to the limited number of studies that test competitive transfer with robust designs.^{43,44}

3.1.3. Perceptual training, visual search, and situational awareness

Virtual reality has also been used to train perceptual processes relevant to basketball, including visual perception and attention allocation under dynamic conditions. Narrative synthesis focused on visual perception highlights that VR can manipulate visual cues and task constraints in ways that are difficult to consistently reproduce in real practice, which is theoretically aligned with training attentional control and cue utilization.⁸ However, VR-specific perceptual issues, including depth perception calibration and display limitations, introduce a methodological challenge: improvements may reflect adaptation to the simulation environment rather than generalizable perceptual-cognitive skill.⁴⁵

A stronger mechanism-oriented synthesis, therefore, distinguishes between (a) training effects that plausibly improve cue pickup in representative contexts and (b) task-specific adaptation to VR constraints.⁹ This distinction is often missing in primary studies. In addition, because cognitive-perceptual performance in basketball is tightly coupled to cognitive load and contextual stressors, studies should increasingly integrate load monitoring or validated indicators of cognitive strain to clarify whether VR improves decision quality under pressure or merely improves task performance in laboratory-like conditions⁴⁶ (Table 2).

3.1.4. Virtual reality for pressure exposure and psychological preparedness

A distinctive advantage of VR is the ability to standardize pressure exposure. In principle, VR can embed time pressure, evaluative cues, and stressor intensity in a graded manner, allowing repeated rehearsal of regulation strategies at the precise moment pressure is experienced. This rationale parallels the clinical evidence that VR exposure approaches can reduce anxiety symptoms under controlled conditions, although sport performance contexts require careful translation rather than direct generalization. Pilot studies in sport have also explored VR relaxation approaches to reduce anxiety and support performance readiness, though the strength of such evidence depends on design rigor and the extent to which outcomes are assessed beyond brief, self-reported changes.^{47,48}

Table 1. Virtual reality mechanism map

Virtual reality (VR) use case and protocol features	Primary empowerment constructs targeted	Mechanism rationale	Expected outcomes	Typical constraints and boundary conditions	Key sources
Interactive tactical decision training using head mounted display, representative offensive plays, time constrained responses, feedback on option selection	Attentional control and cue utilization, cognitive appraisal under pressure, self-efficacy	Repeated exposure to representative cues strengthens selection of task relevant information and speeds perception action coupling; successful rehearsal supports mastery experiences and perceived control	Improved decision accuracy and speed on trained and near transfer scenarios; higher confidence in reads under time pressure	Transfer to real competition is often under tested; outcomes may be simulation bound; short interventions; small samples; comparator heterogeneity	Pagé <i>et al.</i> , ¹⁰ Chan <i>et al.</i> , ⁴⁵ Neumann <i>et al.</i> ⁷
Action aware or artificial intelligence supported VR decision systems with performance analytics, adaptive scenario selection, feedback loops	Attentional control, self-regulation routines, self-efficacy	Feedback and adaptivity can maintain optimal challenge and reinforce regulation routines at decision points	Improved decision metrics within VR; feasibility signals for adaptive training	Evidence commonly prototype or feasibility; limited independent replication; real game transfer rarely demonstrated	Tsai <i>et al.</i> , ⁴² Tsai <i>et al.</i> ⁴³
Visual perception and situational awareness training using controlled manipulation of visual cues, scanning demands, and perceptual constraints	Attentional control and cue utilization, self-regulation of focus	VR can standardize cue rich environments and train selective attention under controlled complexity	Improved perceptual decision performance and scanning behaviors in representative tasks	Risk of VR specific adaptation rather than generalizable skill; depth perception and display constraints; need validated transfer outcomes	Witte <i>et al.</i> , ⁸ Neumann <i>et al.</i> ⁷
Pressure exposure simulation including countdown clocks, crowd noise, evaluative framing, graded stressor intensity	Cognitive appraisal under pressure, self-regulation, self-efficacy, resilience	Standardized exposure may reduce novelty and threat appraisal; coupling exposure with coping routines supports perceived control and rapid recovery after errors	Reduced pressure reactivity; improved performance stability under pressure, when regulation routines are trained and implemented	Pressure induction is often not validated; large variation in stressor fidelity; limited measurement of appraisal, self-efficacy, or resilience as constructs	Carl <i>et al.</i> , ⁴¹ Chan <i>et al.</i> , ⁴⁵ Neumann <i>et al.</i> ⁷
VR relaxation or down regulation sessions delivered as brief calming environments or guided relaxation	Self-regulation, cognitive appraisal, perceived control	Acute down regulation may reduce state anxiety and support readiness; may scaffold later application during competition	Reduced state anxiety; improved readiness, possible performance stabilization	Evidence is often pilot level or abstract; short term outcomes; performance effects may be indirect	Harrison <i>et al.</i> , ⁴⁷ Carl <i>et al.</i> ⁴¹
VR balance and movement control tasks including exergame style balance challenges and feedback on weight shift	Self-regulation of arousal and focus, self-efficacy	Engagement and feedback may improve adherence and perceived mastery in repetitive balance training	Improved balance related test outcomes; potential injury relevant benefits	Basketball specific evidence may be limited; transfer to injury incidence or in game movement not consistently tested	Neumann <i>et al.</i> , ⁷ Witte <i>et al.</i> ⁸

Table 2. Virtual reality evidence table presenting study-level summaries with qualitative evidence weighting and transfer indicators

Source	Type	Primary sport context	VR application focus	Typical outcomes reported	Transfer indicators	Key limitations and bias signals	Qualitative evidence weight
Neumann <i>et al.</i> ⁷	Systematic review	Multi-sport	Interactive virtual reality (VR) applications for sport training	Mixed, depends on sport and task; emphasizes interactive VR potential	Transfer evidence variable, often limited or inconsistently tested across included studies	Heterogeneity in VR fidelity, dose, outcomes, comparators; transfer often under assessed	Moderate to higher for synthesis value, dependent on included study quality
Chan <i>et al.</i> ⁴⁵	Systematic review	Basketball	VR applications in basketball training	Tactical and perceptual cognitive training emphasis; reports current applications and gaps	Transfer to competition likely limited or uneven across included studies	Dependent on primary study quality; heterogeneity in tasks and outcomes; inconsistent ecological validity	Higher for basketball specific synthesis, with cautious interpretation of primary evidence
Pagé <i>et al.</i> ¹⁰	Primary empirical	Basketball	Interactive video simulations and VR decision training	Decision making performance improvements reported	Near transfer reported, generalization to novel plays; competition transfer not consistently demonstrated in the literature	Typical constraints for this literature include limited sample size, short duration, and reliance on task-based decision outcomes	Moderate
Tsai <i>et al.</i> ⁴³	Conference proceeding	Basketball	Action aware VR decision training system	Decision performance within system; system feasibility emphasis	Transfer indicators typically near transfer within task context	Short format, limited methodological detail in proceedings; replication and external validation limited	Lower
Tsai <i>et al.</i> ⁴²	Empirical, engineering oriented	Basketball	Artificial intelligence and VR feasibility for decision training	Feasibility and performance signals in VR decision tasks	Transfer indicators primarily within system; competition transfer typically not demonstrated	Feasibility scope; limited ecological transfer testing; depends on sample and comparator rigor	Moderate
Witte <i>et al.</i> ⁸	Narrative review	Multi-sport	VR sport training with focus on visual perception	Summarizes perceptual training potential and constraints	Transfer discussed conceptually, empirical evidence variable	Narrative scope can increase subjectivity if not systematically bounded; depends on included evidence base	Moderate
Harrison <i>et al.</i> ⁴⁷	Conference abstract, pilot evidence	Soccer, female players	VR relaxation intervention	Anxiety and performance readiness outcomes discussed	Transfer to performance not clearly established in abstract format	Abstract only, limited methodological reporting; likely small sample and short duration	Lower
Carl <i>et al.</i> ⁴¹	Meta analysis of randomized controlled trials (RCTs)	Clinical anxiety disorders	VR exposure therapy	Robust anxiety symptom reduction across RCTs	Transfer to sport performance is indirect, not tested	Context differs from sport, outcomes clinical; useful for mechanism plausibility, not sport efficacy	Higher for anxiety exposure mechanism plausibility, indirect for basketball

Mechanistically, pressure-oriented VR would be expected to support empowerment through changes in appraisal and regulation. First, repeated exposure can reduce novelty and threat appraisal by increasing familiarity with pressure cues. Second, successful performance while implementing coping routines can strengthen self-efficacy and perceived control. Yet current studies often fail to validate whether the VR scenario elicits a robust pressure response, and they rarely measure appraisal, self-efficacy, or regulation directly. Accordingly, claims about pressure inoculation should be framed as plausible but not definitively established within basketball-specific evidence at present.⁴⁵

3.1.5. Protocol considerations and feasibility in team settings

Virtual reality implementation in basketball requires balancing representativeness with feasibility. Session length and motion content must be managed to reduce cybersickness and attentional fatigue, and scenario complexity should progress systematically from constrained reads to more variable, time-limited patterns. From a protocol standpoint, efficacy is most likely when training is interactive and representative, when feedback targets the intended construct, and when the dose is sufficient to move beyond novelty effects.⁷

Because professional basketball already carries substantial physical and cognitive demands, VR dosage and timing should be integrated with training-load realities to avoid adding cognitive overload to weeks with high match-play strain. At the same time, VR systems can generate granular behavioral and performance data, raising governance considerations.⁴⁰ The broader sport analytics literature emphasizes that high-volume data streams create both opportunities and risks, including privacy, misuse, and problematic incentives, which should be addressed explicitly when VR systems are deployed at scale.⁴⁹

3.1.6. Evidence gaps and limitations for virtual reality

Taken together, VR research in basketball supports a cautiously optimistic conclusion: VR can plausibly enhance perceptual-cognitive skills relevant to decision-making and situational awareness, and it offers a theoretically compelling platform for graded exposure to pressure and rehearsal of regulation routines. However, the evidence base remains constrained by heterogeneity in VR fidelity and task design, frequent reliance on proxy outcomes, limited long-term follow-up, and inconsistent tests of ecological transfer to competitive performance.¹⁰ In line with our methods, we therefore interpret VR findings using qualitative evidence weight. Convergent patterns supported by controlled designs and representative tasks

are emphasized, whereas findings from short, small, or proxy-based studies are treated as preliminary.

3.2. Biofeedback for autonomic control and performance consistency

3.2.1. Overview

This subsection addresses Guiding Question (i) by specifying empowerment-relevant mechanisms plausibly trained via HRV biofeedback and EEG neurofeedback, and Guiding Question (ii) by evaluating protocol characteristics, feasibility constraints, and the current strength of evidence for basketball-relevant performance and well-being outcomes.

Biofeedback in sports usually refers to training athletes to become aware of and control physiological processes that are linked to stress and performance states.⁵⁰ The two modalities most explored for performance are HRV biofeedback (sometimes called respiratory or cardiac coherence training) and EEG neurofeedback.⁵¹ Both aim to improve an athlete's ability to self-regulate: HRV training targets autonomic nervous system control via breathing, while EEG training targets brain states associated with focus or relaxation.⁵² For basketball players, biofeedback is typically positioned as a method to support calmer clutch performance, faster recovery after intense plays, improved concentration in high-pressure moments, and potentially improved recovery off court through reduced chronic stress.

From a psychological empowerment perspective, biofeedback is most plausibly linked to perceived control and effectiveness in self-regulation. Mechanistically, biofeedback can strengthen interoceptive awareness and arousal regulation, thereby supporting attentional control and adaptive cognitive appraisal under pressure. In addition, mastery experiences during training can strengthen self-efficacy, especially when athletes learn that they can reliably down-regulate arousal and recover quickly after errors.¹⁹ However, these mechanisms should not be assumed. They need to be supported by direct measurement of constructs such as self-efficacy, appraisal, or attentional control (rather than inferred only from physiological change³⁶ (Table 3).

3.2.2. Heart rate variability biofeedback, mechanisms, evidence, and trustworthiness

Heart rate variability biofeedback typically involves teaching an athlete to breathe at a 6-breath/minute pace (or individualized frequency) while providing real-time feedback (such as a moving graph or coherence score) to indicate when their heart rhythm becomes more sinusoidal and coherent.⁵³ This resonance breathing maximizes the

amplitude of HRV oscillations and engages the baroreflex, effectively strengthening parasympathetic (vagal) activity. Through repeated practice, athletes learn to enter a more relaxed and physiologically efficient state at will.⁵⁴

A systematic review by Jiménez Morgan and Molina¹⁵ concluded that HRV biofeedback is generally feasible and often associated with improved psychophysiological and performance-related outcomes, although evidence quality varies across studies and sports. This point is critical for interpretation. Review-level conclusions can be informative, but the underlying primary studies frequently differ in design rigor, comparator quality, and outcome validity, which limits how confidently one can generalize effects to competitive basketball.¹¹

In the context of basketball, a recent controlled trial by Göçmen *et al.*⁴⁸ provides compelling evidence: over a 10-week period, one group of young players did their normal basketball training plus HRV biofeedback sessions, while a control group did only the basketball practice. The biofeedback group significantly improved their free-throw shooting performance compared to controls and also showed enhanced HRV metrics (greater vagal tone) and even a decrease in breathing frequency during performance.⁵⁵ This suggests that HRV biofeedback training taught them how to remain physiologically calmer (slower breathing, more HRV) under pressure, resulting in better motor execution (free throws). Notably, these players were 18–24 years old and presumably had no prior specialized mental training, indicating HRV biofeedback can add value on top of regular training for even competition-age athletes.⁵⁶

Another study by Tosti *et al.*⁵⁷ looked at basketball skill performance with HRV biofeedback and found improvements in some skills and in parasympathetic indices, reinforcing that such training is not just about subjective feelings but has objective performance correlates.⁵⁸ The idea of performance consistency comes up frequently: coaches often observe that players who can control their arousal have more consistent outputs (e.g., their shooting percentage does not swing wildly game to game, they recover from mistakes faster). Biofeedback directly addresses this by providing athletes with a tool to manage their arousal levels.⁵⁹

Beyond acute performance, HRV monitoring is used in basketball to support holistic adaptation by tracking players' recovery between training sessions and games.^{58,60} Sánchez *et al.* call HRV “the golden nugget of holistic adaptation” in basketball because it reflects internal load and readiness. Biofeedback can acutely reduce stress and anxiety levels, and over time, perhaps improve baseline HRV, which would mean a more resilient athlete.¹² One

interesting study compared a standard HRV biofeedback session with immersing participants in a relaxing VR nature environment (without biofeedback); both groups showed similar reductions in stress and anxiety, especially in those with high initial stress.⁴⁵ This implies that HRV biofeedback is effective partly because it acts as a relaxation training. It also suggests there are multiple ways to induce that beneficial relaxed state.

3.2.3. Electroencephalography neurofeedback, focus training, and evidence limits

In EEG neurofeedback, athletes receive real-time feedback on neural activity, commonly using frequency bands or ratios associated with relaxed focus or sustained attention. Protocols often target states such as calm alertness, for example, through sensorimotor rhythm training, or reduce patterns associated with mind wandering or excessive arousal. The proposed performance pathway improved attentional stability and reduced anxiety-related cognitive interference during precision tasks.⁶¹

Reviews and syntheses describe protocols and report performance-related benefits in some contexts, yet designs vary widely, outcome measures are heterogeneous, and blinding and comparator conditions are often limited. A recent sport-focused synthesis emphasizes that neurofeedback protocols differ substantially in their targets, doses, and transfer tasks, making it difficult to claim a uniform effect across sports or to generalize confidently to basketball-specific outcomes.⁵⁰ Meta-analytic summaries in this area often indicate small to moderate effects with substantial heterogeneity, which reinforces the importance of evidence-weight interpretation rather than uncritical citation.^{16,62}

For basketball, the conceptual fit is strongest in set-play situations such as free throws, where athletes can implement a brief, regulated routine before execution. However, direct basketball metrics in neurofeedback trials remain limited, and many outcomes are derived from laboratory tasks rather than in-game indicators. As a result, the most defensible conclusion is that neurofeedback may support attentional control and arousal stability, but basketball-specific efficacy and ecological transfer require stronger controlled trials with validated performance and empowerment outcomes^{63,64} (Table 4).

3.2.4. Integrating biofeedback with virtual reality and other modalities

An emerging direction is integrating biofeedback with interactive training environments. In principle, coupling HRV biofeedback with representative pressure scenarios could strengthen transfer because athletes practice self-

regulation at the same moments where competitive arousal typically rises. This integration is conceptually aligned with empowerment as perceived control under realistic constraints. At the same time, evidence for combined VR plus biofeedback protocols in basketball remains limited and often preliminary. Where studies report maintenance of performance under cognitive fatigue or stress manipulations, interpretation depends on whether pressure induction is verified and whether comparator conditions rule out expectancy or novelty effects. Therefore, integration should be framed as promising, with conclusions explicitly tied to evidence weight and with clear identification of remaining gaps.⁴⁵

3.2.5. Practical implementation of biofeedback

Introducing HRV biofeedback to a team can be straightforward with today's technology, as many teams already have players wearing heart rate sensors.⁴⁷ Short resonance breathing sessions (e.g., 5–10 min) can be scheduled before or after practices, or as part of warm-ups. Some teams use biofeedback as a recovery tool: for example, after a high-intensity drill, players might do a 2-min guided breathing (with a coach or an app) to bring heart rates down more quickly, aiming to simulate game demands with brief pauses (free throws, timeouts) to recover. Over time, this trains faster recovery, both physical and mental.⁶⁵

However, implementation should be guided by both feasibility and cyber-ethical governance. Wearable systems generate sensitive psychophysiological data, and the broader sport and health analytics literature highlights that large-scale monitoring creates benefits and risks, including privacy vulnerabilities, misinterpretation, and perverse incentives if data are used punitively rather than supportively.⁴⁰ Assistive wearable technologies can support mental well-being when deployed with a clear purpose and user-centered design, but governance and consent are prerequisites for ethical use.⁴⁴ Accordingly, biofeedback should be framed as autonomy-supportive skill development, with transparent consent, data minimization, and clear boundaries on who can access individual-level metrics.⁵⁷

3.2.6. Feasibility, adherence, and athlete buy-in

Biofeedback uptake can be limited by perceived burden or skepticism. Evidence-informed strategies to support adherence include short sessions, individualized targets, and explicit linkage to performance-relevant outcomes, while avoiding coercive or surveillance-like framing. Neurofeedback typically requires more equipment and specialized expertise, which can reduce feasibility at the team level compared with HRV protocols.⁶¹

3.2.7. Gaps, cautions, and implications for interpretation

One recurring gap is long-term adherence and retention of regulation skills. Device heterogeneity and measurement validity are also critical, as unreliable sensors can undermine an athlete's trust and lead to misinformed decisions. Another limitation is ecological transfer; athletes may demonstrate regulation in a quiet setting but fail to implement it under competitive noise and time pressure. Protocols that include representative stressors and explicit application training are therefore likely to be more transferable than protocols delivered only in calm environments.^{66,67}

In sum, biofeedback can empower athletes by strengthening tangible control over mind-body states. HRV biofeedback has the most direct basketball-relevant evidence for improving arousal regulation and performance stability under pressure, whereas EEG neurofeedback is promising for attentional control but remains limited by protocol heterogeneity and a lack of basketball-specific transfer testing. Both modalities should be interpreted through mechanism-based, evidence-weighted synthesis and embedded within autonomy-supportive, ethically governed monitoring practices.

3.3. Mindfulness for attention, acceptance, and flow

3.3.1. Performance outcomes with a basketball lens, free throws under pressure

This subsection addresses Guiding Question (i) by specifying empowerment-relevant mechanisms targeted by mindfulness interventions, and Guiding Question (ii) by evaluating protocol characteristics, feasibility, and the strength of evidence for basketball-relevant performance and well-being outcomes.

Mindfulness-based interventions in sports range from brief guided meditations to multi-week programs such as mindfulness-acceptance-commitment or mindful sport performance enhancement.⁶⁸ In basketball, applications have included pre-performance centering exercises, weekly in-season mindfulness sessions, and encouraging athletes to develop daily meditation habits. The goals are typically to improve concentration, reduce performance anxiety, enhance the ability to enter flow states, and increase overall psychological well-being (such as reducing stress or burnout).⁶⁹

From a psychological empowerment perspective, mindfulness is best conceptualized as a mechanism-focused intervention rather than a generic wellness activity. The most relevant constructs include attentional control and meta-awareness, namely noticing distractions

and restoring task focus, acceptance and psychological flexibility, namely allowing internal experiences without reactive avoidance, and cognitive appraisal under pressure, namely reducing threat-based interpretations and self-evaluative rumination.⁷⁰ These processes can support self-regulation during performance, especially in pressure-sensitive tasks, and can strengthen self-efficacy indirectly through more consistent routines and perceived control over attentional and emotional responses. Importantly, these mechanisms should be evaluated explicitly rather than inferred solely from improvements in general well-being⁷¹ (Table 5).

3.3.2. Performance outcomes with a basketball lens, free throws under pressure

The trustworthiness of the performance evidence varies. Some studies are quasi-experimental and may be vulnerable to expectancy effects, uncontrolled co-interventions, or limited blinding, which can inflate observed benefits. Conversely, null findings are informative and should be integrated rather than minimized.⁷² A brief body scan intervention administered in a professional female basketball context did not improve HRV recovery or cognitive task outcomes beyond an active control, indicating that ultra-brief dosing or poorly matched timing may be insufficient in experienced athletes. Taken together, the evidence supports the plausibility of mindfulness benefits for pressure-sensitive precision tasks, but effect patterns appear contingent on dose, athlete context, and the extent to which practice is integrated into routines rather than delivered as a single exposure.^{67,73}

3.3.3. Flow relevant processes, attention stability, and rapid refocusing

Many athletes describe mindfulness as helping them enter “the zone” more readily. Flow, when fully absorbed and effortless, has been linked to mindfulness in multiple studies. For example, studies found that increasing trait mindfulness (through an intervention) was associated with higher self-reported flow in elite athletes. Mechanistically, mindfulness improves meta-awareness (awareness of where one’s attention is) and attentional refocusing skills.⁷⁴ In basketball, this could mean a player notices their mind wandering after a bad call and swiftly refocuses on their defensive assignment, rather than stewing and missing a rotation.⁷⁵

A meta-analysis found that athletes with higher mindfulness had fewer performance-degrading worries, supporting the idea that mindfulness inoculates against the kinds of cognitive intrusions that break flow. Furthermore, mindfulness can enhance preshooting routines and consistency.²¹ By teaching non-reactivity, a mindful athlete

is less likely to rush or alter their routine due to a previous miss or a noisy distraction. This aligns with findings that high mindfulness was linked to stable routines and better free-throw outcomes, and that high arousal interfered with those who lacked mindfulness. In essence, mindfulness helps keep arousal at an optimal level, not too low (drowsy) but not too high (panicky), which is crucial for fine motor tasks like shooting.⁷⁶

3.3.4. Psychological health outcomes, stress physiology, and burnout relevant indicators

From a health perspective, mindfulness interventions among athletes have shown benefits such as reduced stress, improved mood, and even reductions in indicators of burnout.^{24,25} Studies of young basketball players reported qualitative feedback that athletes felt more resilient and focused, and quantitative data suggested reduced stress and improved emotional regulation capacity (though sample size was small).⁵⁵ Mindfulness can thereby function as a protective factor for mental health by providing tools to handle the pressures of competition and high training loads.²⁴ However, as Wang *et al.*’s⁷⁴ meta-analysis concluded that MBIs clearly improve mindfulness levels and often performance-related mental factors, their direct effect on general mental health outcomes (like generalized anxiety or overall well-being) in athletes has not always been significant. This could be due to heterogeneity or because the interventions were not targeting clinical levels of distress. In practical terms, mindfulness is beneficial for performance empowerment and day-to-day stress management, but it should not be regarded as a universal solution for all mental health issues an athlete might face (serious issues might still require counseling or other interventions).⁷⁷

3.3.5. Protocol notes, implementation, and boundary conditions

Mindfulness programs can be implemented through structured multi-week sessions or through micro-practices integrated into training routines. From a mechanism standpoint, protocols should be selected and evaluated based on the targeted construct. If the aim is attentional control, practice should train notice-and-refocus cycles under mild distraction. If the aim is cognitive appraisal under pressure, practice should explicitly address evaluative thoughts and threat interpretations. If the aim is resilience and recovery after mistakes, practice should include acceptance and recommitment to task-relevant cues.⁷⁸

Feasibility and adherence are critical boundary conditions. Brief interventions may be operationally attractive, but the null findings among professional players

Table 3. Biofeedback mechanism map linking protocol features to empowerment constructs, expected outcomes, and typical constraints

Biofeedback application and protocol features	Primary empowerment constructs targeted	Mechanism rationale	Expected outcomes	Typical constraints and boundary conditions	Key sources
Heart rate variability (HRV) biofeedback training using resonance breathing with real time HRV feedback, brief repeated sessions, progressive practice and transfer cues	Arousal regulation, interoceptive awareness, self-efficacy, attentional stability	Feedback supports learning to down regulate autonomic arousal and recover more rapidly, which can strengthen perceived control and confidence in pressure situations	Reduced stress reactivity, improved recovery readiness, more stable execution in pressure sensitive tasks	Device validity varies, adherence can be challenging, transfer to noisy competitive contexts often under tested, outcome heterogeneity	Peake <i>et al.</i> , ⁶¹ van der Zwan <i>et al.</i> , ⁶⁶ Lew <i>et al.</i> ⁵³
HRV and workload monitoring for readiness management combining HRV and external load indicators such as accelerometry to inform training adjustment	Perceived control via actionable feedback, autonomy supportive self-regulation when shared transparently, resilience support through recovery planning	Readiness metrics can guide recovery decisions and prevent overload, but empowerment depends on governance, interpretation, and athlete involvement	Improved workload control, reduced overload risk, better recovery planning	Risk of surveillance framing, false positives, data overload, unclear link to injury prevention if monitoring is not truly indicative	Zamora <i>et al.</i> , ⁵¹ Peake <i>et al.</i> , ⁶¹ Jimenez and Verhagen ⁶⁸
Virtual reality (VR) respiratory biofeedback delivering breathing guidance and physiological feedback inside immersive environments	Arousal regulation, attentional control, self-efficacy	VR can increase engagement and context relevance while feedback reinforces effective breathing patterns and perceived control	Improved regulation skill acquisition, reduced stress indices, higher training adherence	Pilot evidence often, cybersickness risk, generalization and dose response not consistently established	Blum <i>et al.</i> ⁵²
Relaxing VR exposure versus HRV biofeedback comparing acute stress and anxiety effects	Cognitive appraisal, arousal regulation, perceived control	Relaxing immersion may reduce stress and anxiety similarly to HRV biofeedback in some contexts, suggesting multiple routes to down regulation	Acute reductions in stress and anxiety, readiness support	Acute effects may not translate to competition, outcomes often short term, limited sport-specific testing	Pratviel <i>et al.</i> ⁵⁷
Mobile VR mindfulness breathing with integrated biofeedback combining guided breathing meditation and physiological feedback	Acceptance and refocusing, arousal regulation, psychological flexibility, self-regulation	Integrated delivery links mindfulness-based skills with measurable physiological change, supporting both perceived control and acceptance-based coping	Improvements in physiological and psychological health indicators, potential readiness benefits	Generalization to sport performance not guaranteed, adherence and device reliability are critical, mechanisms often inferred	Wieczorek <i>et al.</i> ⁶⁰
Biofeedback based VR mindfulness game using game mechanics to reinforce regulation and sustained practice	Self-regulation, attentional control, engagement and adherence, perceived control	Gamified feedback can increase practice dose and skill repetition, supporting regulation skill development through reinforcement	Increased practice adherence, improved mindfulness practice engagement, potential stress regulation benefits	Prototype stage evidence, limited independent replication, transfer to sport outcomes not established	Lu <i>et al.</i> ⁶⁷

(cont'd...)

Table 3. (Continued)

Biofeedback application and protocol features	Primary empowerment constructs targeted	Mechanism rationale	Expected outcomes	Typical constraints and boundary conditions	Key sources
Electroencephalography neurofeedback for calm focused performance targeting sensorimotor rhythm or alpha rhythms with repeated sessions and sport specific transfer tasks	Attentional control, arousal stability, self-efficacy, cognitive appraisal under pressure	Neurofeedback may shape attentional stability and reduce disruptive arousal, supporting perceived control during precision execution	Improved precision performance and attentional stability in some sports, possible anxiety reduction	Protocol heterogeneity, comparator limitations, expectancy effects, limited basketball specific evidence, requires expertise and time	Cheng <i>et al.</i> , ⁵⁶ Gong <i>et al.</i> , ⁶⁴ Tosti <i>et al.</i> , ⁵⁹ Davelaar ⁶⁹
Technology integration and applied delivery in high performance settings including staffing, workflow, and athlete engagement practices	Autonomy support, perceived control, self-regulation adoption	Implementation quality shapes whether biofeedback is experienced as empowering skill development or as external control	More sustainable adoption, better adherence, clearer role boundaries	Resource demands, practitioner expertise, governance requirements	Lew <i>et al.</i> ⁵³
Contextual moderator: mental fatigue and cognitive load in high demand sport environments shaping when regulation skills may be most valuable	Attentional control under fatigue, self-regulation, resilience	Mental fatigue degrades decision quality and performance, increasing the need for reliable regulation routines and recovery planning	Reduced performance decrement risk when regulation and recovery are timed appropriately	Biofeedback specific mitigation effects often not directly tested, requires integrated design and ecological outcomes	Cao <i>et al.</i> , ⁶⁵ Gantois <i>et al.</i> ⁶³
Well-being and resilience context in basketball linking burnout related outcomes to needs satisfaction and resilience	Resilience, self-regulation, autonomy and competence support	Well-being constructs frames why stress regulation and governance matter, especially when monitoring could undermine autonomy	Better alignment of interventions with well-being outcomes and motivational climate	Not biofeedback evidence per se, but relevant for interpreting outcomes and ethical trade offs	Kostopoulos <i>et al.</i> ⁷³

suggest that minimal dosing may not reliably shift stress recovery or cognitive outcomes. Conversely, longer programs may yield more robust skill acquisition but require coach support, scheduling, and credible framing to avoid being perceived as generic wellness content rather than performance-relevant training^{45,69} (Table 6).

3.3.6. Trustworthiness, evidence gaps, and implications for interpretation

An interesting finding is that athletes with certain personality traits or who play certain sports may benefit differently. For example, those high in perfectionism might initially struggle with mindfulness (because they judge themselves for having thoughts), but ultimately, they may particularly benefit by learning to let go.⁷⁹ Mindfulness might also interact with team culture; if a team is highly receptive and a coach models it (e.g., by participating in or referencing mindfulness concepts in pep talks), it normalizes the practice. In contrast, if an athlete is the only one doing it, they might feel awkward or not persist with

it. Fortunately, mindfulness in sports has become common enough that stigma is low.¹⁶

3.3.7. Null findings and considerations

We already discussed null results for ultra-brief interventions. Another study found that a very short pre-game mindfulness exercise did not significantly improve performance among professional players, which could imply that pros might need either more intensive training or that, at their level, mental skills are already well-developed by other means. The dosage and timing seem key: a single brief session may be insufficient except in experiments with novices, whereas a sustained practice yields cumulative effects.⁸⁰

Additionally, not all athletes readily take to mindfulness. Some may prefer active meditation, such as yoga or mindful movement, rather than sitting still. Others might resist the introspective aspect. Thus, delivering the training in a sport-specific way (using language athletes relate to,

Table 4. Biofeedback evidence table presenting study-level summaries with qualitative evidence weighting and transfer indicators

Source	Type	Primary context	Modality focus	Primary endpoints reported	Transfer indicators	Key limitations and bias signals	Qualitative evidence weight
Zamora <i>et al.</i> ⁵¹	Original empirical study	Men's basketball	Heart rate variability (HRV) plus accelerometry for workload control	Workload and readiness management indicators	Not an intervention transfer test, monitoring oriented	Observational and applied monitoring context, inference depends on measurement validity and decision rules	Moderate for monitoring relevance, indirect for empowerment effects
Peake <i>et al.</i> ⁶¹	Critical review	Physically active populations	Consumer wearables and apps for biofeedback, stress and sleep	Device and application capabilities, limitations, validity issues	Not applicable	Heterogeneous products, rapidly evolving market, highlights validity and interpretability risks	Higher for device validity and implementation constraints
Jimenez and Verhagen ⁶⁸	Conceptual critique and perspective	Athlete monitoring and injury prevention	Monitoring frameworks and validity concerns	Limits of current monitoring and injury prevention claims	Not applicable	Not primary efficacy testing, focuses on conceptual and governance issues	Moderate to higher for governance and inferential caution
van der Zwan <i>et al.</i> ⁶⁶	Randomized controlled trial	Non athlete sample	HRV biofeedback training	Mental health related outcomes	Indirect for sport	Context not sport, outcomes not basketball specific, but strong design for mechanism plausibility	Higher for HRV mental health mechanism plausibility, indirect for basketball outcomes
Blum <i>et al.</i> ⁵²	Development and pilot study	General sample	Virtual reality (VR) respiratory biofeedback	Feasibility and biofeedback related outcomes	Indirect for sport	Pilot scope, limited sample, transfer to performance not established	Moderate to lower
Pratviel <i>et al.</i> ⁵⁷	Experimental comparison	General sample	Relaxing VR immersion versus HRV biofeedback	Stress and anxiety effects	Indirect for sport	Acute outcomes, limited sport specific measures, transfer not tested	Moderate
Wieczorek <i>et al.</i> ⁶⁰	Replication study	General sample	Mobile VR mindfulness breathing with integrated biofeedback	Physiological and psychological health effects	Indirect for sport	Transfer to sport performance not tested, adherence and context variability	Moderate
Lu <i>et al.</i> ⁶⁷	Conference proceedings	General sample, design context	Biofeedback based VR mindfulness game	Engagement and mindfulness practice support outcomes	Indirect for sport	Prototype emphasis, limited efficacy testing, replication needed	Lower

(cont'd...)

Table 4. (Continued)

Source	Type	Primary context	Modality focus	Primary endpoints reported	Transfer indicators	Key limitations and bias signals	Qualitative evidence weight
Cheng <i>et al.</i> ⁵⁶	Experimental sport study	Golf	Sensorimotor rhythm neurofeedback	Putting performance outcomes	Direct to sport task, not basketball	Sport specific but not basketball, protocol specificity limits generalization	Moderate to Higher for neurofeedback performance signal, indirect for basketball
Gong <i>et al.</i> ⁶⁴	Experimental sport study	Shooting	Sensorimotor rhythm versus alpha neurofeedback	Shooting performance and neuroplasticity related outcomes	Direct to sport task, not basketball	Protocol and population specificity, generalization to basketball unclear	Moderate for performance signal, indirect for basketball
Tosti <i>et al.</i> ⁵⁹	Systematic review	Multi-sport	Neurofeedback protocols in sport	Performance, anxiety, emotional regulation	Transfer varies across included studies	Heterogeneity in protocols and outcomes, depends on primary study quality	Moderate to higher for synthesis value, with cautious inference
Davelaar ⁶⁹	Theory and mechanisms paper	General neuroscience	Neurofeedback mechanisms	Mechanistic explanation, computation theoretic framing	Not applicable	Not an efficacy study, supports interpretation rather than outcomes	Higher for mechanistic clarification, indirect for sport efficacy
Lew <i>et al.</i> ⁵³	Book chapter	High performance sport setting	Technology integration in sport psychology	Applied implementation considerations	Not applicable	Chapter level synthesis, context specific, not a controlled efficacy source	Moderate for implementation guidance

such as “stay in the play” instead of Zen terminology) can improve buy-in.²³

To sum up, mindfulness interventions in basketball show clear benefits in improving attentional focus, reducing competitive anxiety, enhancing resilience to stress, and even boosting certain performance outcomes (especially precision skills under pressure).^{20,71} Mindfulness works through fostering present-moment awareness and acceptance, which prevents the cognitive and emotional disturbances that often derail performance. It is a low-cost, low-risk intervention that can be implemented with a modest time commitment (a few minutes a day or an hour a week) and has broad-ranging positive side effects on athlete health.

3.4. Integrative and artificial intelligence-enhanced pathways

This subsection addresses Guiding Question (i) by integrating empowerment mechanisms across VR, biofeedback, and mindfulness, Guiding Question (ii) by evaluating the strength and limits of current multimodal evidence, and Guiding Question (iii) by positioning AI as a realistic implementation layer with explicit governance safeguards. Having examined each pillar separately, it becomes evident that these methods can be complementary when they are integrated around a shared mechanism logic rather than delivered as disconnected techniques. A comprehensive mental training program for basketball could weave together VR, biofeedback, and mindfulness into a cohesive whole, with AI as a facilitator to personalize

Table 5. Mindfulness mechanism map linking protocol features to empowerment constructs, expected outcomes, and typical constraints

Mindfulness application and protocol features	Primary empowerment constructs targeted	Mechanism rationale	Expected outcomes	Typical constraints and boundary conditions	Key sources
Mindfulness training for pressure shooting with structured practice plus application at free throw line	Attentional control, cognitive appraisal under pressure, self-regulation, self-efficacy	Reduced maladaptive self-focus and improved refocusing can stabilize execution under evaluative pressure, repeated success supports perceived control	Improved free throw performance under stress, reduced nervousness and pressure disruption	Comparator variability, expectancy effects, transfer beyond test context often limited, dose response unclear	Wang & Zhang; ⁷⁴ Wang <i>et al.</i> ⁷⁸
Brief mindfulness exposure such as a single short body scan delivered at halftime or pregame	State regulation, attentional settling	Acute relaxation or centering may occur, but skill acquisition is unlikely with minimal dose	Mixed effects may not improve heart rate variability recovery or cognition in elite contexts	Very dose limited, timing may be suboptimal, athlete readiness and skepticism may moderate effects	Aras <i>et al.</i> ⁷²
Mindfulness and acceptance-based program for youth elite players with emphasis on how and for whom it works	Acceptance, psychological flexibility, resilience, self-regulation, appraisal	Acceptance reduces avoidance and rumination, supports rapid recovery after mistakes, mechanism focus clarifies moderators	Potential improvements in coping and performance related functioning, mechanism insights	Exploratory designs, smaller samples, reliance on self-report common, need replication	Goisbault <i>et al.</i> ⁷⁷
Mindfulness for performance program with structured sessions and performance-oriented skills	Attentional control, acceptance, self-regulation, self-efficacy	Integrates mindfulness skills into performance routines and cognitive control	Improvements in psychological skills and performance outcomes in some contexts	Heterogeneity across sports, mechanisms not always directly measured, implementation fidelity matters	Tebourski <i>et al.</i> ⁵⁴
Mindfulness training and stress physiology in wheelchair basketball competition contexts	Arousal regulation, appraisal, perceived control	Practice may attenuate stress response during competition, supporting well-being relevant regulation	Lower cortisol reactivity during competition, potential well-being benefit	Small samples typical, generalization to other populations requires caution	MacDonald and Minahan ⁶²
Well-being context and burnout related constructs in basketball informing interpretation and boundary conditions	Resilience, autonomy and competence support, recovery processes	Burnout associations highlight why regulation and supportive climates matter for well-being and sustainable performance	Better targeting of interventions to well-being outcomes	Not mindfulness efficacy evidence per se, but informs mechanism and ethical framing	Kostopoulos <i>et al.</i> ; ⁵⁵ Rachiotis <i>et al.</i> ; ⁷¹ Madigan <i>et al.</i> ⁸¹

Table 6. Mindfulness evidence table presenting study-level summaries with qualitative evidence weighting and transfer indicators

Source	Type	Basketball context	Intervention and dose features	Outcomes reported	Transfer indicators	Key limitations and bias signals	Qualitative evidence weight
Wang and Zhang ⁷⁴	Intervention study	Basketball players	Mindfulness training applied to stressful free throw conditions	Free throw performance under stress and related psychological indicators	Basketball-relevant task transfer, competition level transfer unclear	Design details determine inference, potential expectancy effects, need longer follow-up	Moderate
Wang <i>et al.</i> ⁷⁸	Quasi-experimental study	Male collegiate basketball athletes in Macau	Mindfulness intervention targeting psychological skills and shooting performance	Psychological skills and shooting outcomes	Basketball-relevant task outcomes reported	Quasi-experimental design, comparator quality and blinding unclear	Moderate to lower
Aras <i>et al.</i> ⁷²	Experimental study	Female professional basketball players	Brief body scan practice, single short dose	Heart rate variability recovery and cognitive task outcomes, null effects	No evidence of performance transfer, provides boundary condition	Very brief dose, acute timing, may not test skill acquisition	Moderate
Goisbault <i>et al.</i> ⁷⁷	Exploratory program evaluation	Young elite female basketball players	Integrated mindfulness and acceptance-based program	Mechanism and moderator focused outcomes, how and for whom	Focus on mechanisms and individual differences, performance transfer unclear	Exploratory design, sample size constraints typical, replication needed	Moderate
MacDonald and Minaha ⁶²	Competition focused study	Highly trained wheelchair basketball players	Mindfulness training prior to competition	Cortisol response attenuated in competition	Physiological regulation in competitive context, performance outcomes indirect	Sample size typical for elite samples, generalization limits	Moderate to higher for physiological outcome relevance
Tebourski <i>et al.</i> ⁵⁴	Program evaluation review or trial	Multi-sport	Mindfulness for Performance program	Sport performance outcomes reported	Transfer depends on sport and measures	Heterogeneity, mechanism measurement variability	Moderate
Madigan <i>et al.</i> ⁸¹	Longitudinal observational	Junior athletes	Motivational pathway linking perfectionism and burnout	Burnout related outcomes	Not an intervention transfer source	Not mindfulness evidence, informs boundary conditions	Moderate for boundary condition framing
Kostopoulos <i>et al.</i> ⁷³	Observational study	Basketball athletes	Burnout, resilience, needs satisfaction associations	Burnout and resilience-related indicators	Not an intervention transfer source	Not mindfulness efficacy, informs well-being logic	Moderate for context framing
Rachiotis <i>et al.</i> ⁷¹	Systematic scoping review	Basketball referees	Burnout evidence base in officiating	Burnout synthesis	Not applicable	Different population, used for broader burnout context only	Lower for player mindfulness inference, moderate for burnout context

and adjust these elements.⁸¹ Conceptually, integration is most defensible when VR provides representative exposure to pressure and decision constraints, biofeedback supports arousal regulation and interoceptive skill acquisition, and mindfulness supports acceptance, attentional stability, and rapid refocusing after distraction. When aligned in this way, the combined program targets perceived control and effectiveness in self-regulation, the core elements of psychological empowerment, while also supporting well-being through improved stress recovery and reduced cognitive interference.

3.4.1. Combined approaches and evidence weight

Multimodal approaches are most often justified by the claim that regulatory skills transfer better when practiced under representative stressors. A key example is experimental work that combines VR-guided mindfulness breathing meditation with integrated biofeedback under conditions of mental fatigue and pressure.²⁵ In this design, cognitive depletion manipulation is used to simulate conditions under which performance typically deteriorates, and the multimodal intervention is evaluated against a comparator condition, providing a clearer basis for causal inference than purely descriptive reports.⁸⁷ This approach is theoretically coherent because it links exposure, regulation practice, and physiological feedback to empowerment mechanisms, including cognitive appraisal under pressure, arousal regulation, and perceived control during execution.⁴⁴

A second integrative line concerns acute downregulation. Immersion in a relaxing VR environment has been associated with reductions in stress and anxiety comparable to those observed following HRV biofeedback, suggesting that different modalities can converge on similar short-term regulation endpoints.⁵⁷ This does not imply equivalence for performance transfer. Rather, it supports the inference that multiple routes can lead to a calmer psychophysiological state, which may be leveraged pragmatically to align with athletes' preferences and improve adherence, provided that downstream outcomes and durability are evaluated.⁴⁵

Trustworthiness appraisal is essential when interpreting multimodal studies. Many integrated interventions are short, rely on laboratory tasks, or include non-basketball samples, which limits ecological inference. Nonetheless, designs that include comparator conditions, direct pressure manipulations, and objective motor outcomes provide more informative evidence than uncontrolled demonstrations. Importantly, the rationale for integration aligns with what is known about mental fatigue and performance decline in high-demand sport contexts. Mental fatigue has been shown to impair technical

performance and alter autonomic responses in elite youth basketball players, supporting the practical relevance of interventions that can preserve regulation and execution under fatigue.⁸³ Systematic evidence also indicates that mental fatigue can impair basketball performance, reinforcing the need to consider timing and context when integrating psychological training with competitive demands⁶⁴ (Table 7).

3.4.2. Artificial intelligence augmentation

Artificial intelligence is best positioned as an implementation and decision support layer rather than as an autonomous system that directly alters athletes' emotional or performance states. In this review, the realistic added value of AI concerns personalization, scheduling, and monitoring of training responses, with human oversight and explicit constraints on claims.²⁹

First, AI can support protocol personalization and adaptive scheduling by integrating data streams commonly available in high-performance settings, including external load and match demands, readiness indicators, and self-reported wellness. Competitive basketball has well-documented variation in match-play demands and training load across levels, which makes individualized planning for cognitive and regulation training particularly relevant. Workload control approaches that combine HRV and accelerometry illustrate how physiological and external load signals can inform readiness management, though such monitoring does not automatically translate into empowerment unless governance is autonomy-supportive and interpretation is transparent.^{48,82}

Second, AI can support task-level adaptivity within VR training, for example, adjusting scenario complexity or feedback based on performance patterns. Feasibility studies of VR-based basketball tactic training and AI-supported decision training provide proof of concept that adaptive systems can be built and evaluated, but these studies should be interpreted as feasibility and early efficacy signals rather than definitive evidence of in-game transfer.^{42,43}

Third, AI can support monitoring and feedback dashboards that summarize trends rather than delivering deterministic prescriptions. Monitoring cognitive load in competitive environments, including professional women's basketball, illustrates the broader trend toward quantifying cognitive demands, but such work also highlights the need to interpret indicators conservatively and avoid overreach in claims. Broader commentary on athlete data systems emphasizes that large-scale analytics have substantial potential but also substantial risks, including misinterpretation, privacy concerns, and misuse of metrics, which must be explicitly addressed in any AI-enabled

Table 7. Multimodal integration map linking combined protocols to empowerment constructs, expected outcomes, feasibility constraints, and qualitative evidence weight

Integrated pathway and intended use	Core components	Empowerment constructs targeted	Expected outcomes	Feasibility constraints and governance boundary conditions	Qualitative evidence weight
Pressure performance protection under mental fatigue	VR guided mindfulness breathing plus integrated biofeedback, delivered after cognitive depletion, compared with control condition (Wagner and Wiczorek ⁶⁷)	Arousal regulation, attentional control, cognitive appraisal under pressure, self-efficacy through successful regulation, resilience via rapid recovery after fatigue	Preserved motor performance under pressure following fatigue, improved regulation indices where measured	Requires validated pressure manipulation, comparator rigor, and sport relevant outcome assessment; transfer beyond laboratory paradigm remains uncertain	Moderate to higher
Acute downregulation via alternative routes	Relaxing VR immersion compared with HRV biofeedback for stress and anxiety reduction (Pratviel <i>et al.</i> ⁵⁷)	Arousal regulation, cognitive appraisal, perceived control through rapid calming	Similar acute reductions in stress and anxiety across modalities	Acute effects do not establish competitive transfer; settings are often non sport; outcomes are usually short term	Moderate (for acute regulation), indirect (for basketball transfer)
Immersive respiratory biofeedback to increase engagement	VR respiratory biofeedback prototype, feasibility and pilot outcomes (Blum <i>et al.</i> ⁵³)	Arousal regulation, attentional stability, perceived control and self-efficacy via feedback driven mastery	Improved regulation practice engagement, feasibility signals for biofeedback acquisition	Pilot scope, small samples, limited ecological transfer; cybersickness and hardware constraints; mechanism measures often limited	Lower to moderate
Mobile virtual reality (VR) mindfulness breathing with integrated biofeedback	Guided mindfulness breathing delivered in mobile VR with integrated biofeedback, replication evidence (Wiczorek <i>et al.</i> ⁶⁰)	Acceptance and refocusing, arousal regulation, psychological flexibility, self-regulation	Physiological and psychological health effects, potential readiness benefits	Sport and basketball transfer not demonstrated; adherence and device validity are central; outcomes may be context dependent	Moderate (for health endpoints), indirect (for basketball performance)
Gamified VR biofeedback for mindfulness practice	Biofeedback based VR game to support mindfulness practice (Lu <i>et al.</i> ⁶⁷)	Self-regulation, attentional control, perceived control through reinforcement, adherence	Increased engagement and practice dose, plausible stress regulation benefits	Prototype stage, limited replication, transfer to sport outcomes not established	Lower
Integrated scheduling anchored to match demands and recovery	Combining match-play load knowledge with readiness signals to time regulation training and recovery modules (Petway <i>et al.</i> , ³⁹ Zamora <i>et al.</i> ⁵¹)	Self-regulation planning, perceived control through actionable feedback, resilience through recovery management	Better alignment of regulation modules with high load periods, reduced overload risk	Monitoring must be autonomy supportive; avoid surveillance framing; interpret readiness conservatively; do not overclaim injury prevention (Jimenez & Verhagen, 2025)	Moderate (implementation rationale)
Artificial intelligence (AI) enabled adaptivity inside VR tactical training	VR tactic training feasibility plus adaptive logic, treated as early-stage evidence (Tsai <i>et al.</i> ⁸⁶)	Attentional control, self-efficacy via progressive mastery, self-regulation via feedback guided rehearsal	Improved performance within training tasks, feasibility of adaptive pipelines	Evidence is feasibility oriented; competitive transfer rarely tested; ensure transparency and human oversight	Moderate (feasibility), indirect (transfer)
AI supported cognitive load and monitoring dashboards	Cognitive load monitoring in professional women's basketball and analytics driven decision support (Fuster <i>et al.</i> ⁹)	Self-regulation planning, appraisal under load, resilience via workload management	Identification of high strain periods, better timing of regulation modules	Risk of datafication, monitoring burden, misinterpretation; require privacy by design and clear governance (West <i>et al.</i> ⁴⁰)	Moderate
Ethical and applied integration principles	Technology integration guidance for sport psychology systems, emphasizing boundaries and applied fit (Lew <i>et al.</i> ⁵³)	Autonomy support, perceived control, adherence via credible framing	Higher uptake and sustainable integration, reduced misuse risk	Not efficacy evidence; supports implementation coherence and governance expectations	Moderate (implementation guidance)

implementation.^{83,84}

Accordingly, claims about real-time adaptation of emotional or performance states should be avoided unless directly supported by empirical evidence. Instead, AI should be described as facilitating structured decision support, for example, identifying sustained deviations in readiness indicators, suggesting recovery-oriented modules after high-demand periods, or recommending additional practice for athletes who show consistent regulation breakdown under representative stressors, with final decisions remaining with practitioners and athletes. This framing is consistent with contemporary discussions of technology use in sport psychology, which emphasize applied usefulness, boundaries, and the importance of integrating tools into existing performance systems rather than replacing human judgment.⁸⁵

Artificial intelligence augmentation in elite sport currently spans a continuum from established analytics and simple adaptive algorithms to emerging predictive and real-time multimodal systems. At the present operational end, most applications are descriptive and decision supportive rather than autonomous. Typical examples include baseline-based readiness analytics using HRV, sleep, wellness reports, rule-based thresholds and trend alerts, and integrated dashboards that combine internal and external load signals to guide recovery planning and training adjustments. These approaches can be implemented with transparent logic and human oversight, and they align with the evidence base supporting HRV and workload monitoring as contextual inputs for planning rather than as deterministic prescriptions.^{60,66}

Near-operation applications include task-level adaptivity within training technologies. Examples include VR-based basketball tactics and decision-training systems that adjust scenario difficulty or cue complexity based on performance signals, as feasibility studies have demonstrated. Similarly, integrated VR-based breathing or mindfulness protocols with physiological feedback represent near-operational multimodal training tools that can be deployed as brief regulation modules in controlled contexts. Comparative evidence also indicates that relaxing VR immersion may yield acute reductions in stress and anxiety comparable to HRV biofeedback, supporting preference-matched delivery for short downregulation blocks, but not establishing equivalence for competition-level transfer.^{76,79}

Future prospects involve predictive AI and closed-loop multimodal systems that fuse continuous data streams, such as HRV, load, cognitive strain proxies, and behavioral markers, to forecast periods of elevated risk for performance decline or overload and to recommend

individualized microcycle adaptations. However, these systems require validation under real-world constraints, careful reporting of uncertainty, and governance safeguards to prevent overreach, monitoring burden, and erosion of autonomy. Accordingly, claims about real-time modification of emotional or performance states should be reserved for settings with direct empirical support, while forward-looking use cases should be framed explicitly as prospective and subject to rigorous field evaluation.⁸⁴

3.4.3. Ethical and health considerations in integrated systems

Integration increases both opportunity and risk because multiple data streams and technologies can amplify the monitoring burden and digital load. From a cyberpsychology lens, ethical implementation is not an add-on. It is a core boundary condition for whether these tools support empowerment or undermine it.⁸⁶

First, athlete autonomy and consent should be protected through transparent communication about what data are collected, why they are collected, who has access to them, and how the metrics will be used. Second, data minimization and privacy-by-design principles should be adopted, including a preference for aggregated reporting when possible and clear role boundaries for access to individual data. Third, technology should not be used punitively. If biofeedback and monitoring are framed as surveillance, they can erode trust and shift motivational climates toward external control, undermining empowerment.⁶⁷ Contemporary critiques of athlete monitoring emphasize the risk of overstating the preventive value of monitoring when there are no truly indicative signals, thereby supporting cautious interpretation and governance safeguards.⁷⁷ Finally, integrated programs must avoid becoming an additional burden. In high-demand schedules where mental fatigue impairs performance and alters autonomic responses, the timing and dose of VR exposure, regulation training, and mindfulness practice should be coordinated with training load and recovery priorities rather than added indiscriminately.⁶⁵

In sum, the strongest case for an integrative approach is theoretical and mechanism-based. VR offers representative exposure and rehearsal, biofeedback trains physiological self-regulation, and mindfulness trains acceptance and attentional stability. Early evidence for multimodal combinations is promising but still limited in ecological transfer. AI may enhance implementation through personalization and monitoring when deployed as decision support within robust ethical governance. These conclusions are presented in proportion to the weight of the evidence, with detailed study-level summaries

consolidated in Table 8.

3.4.4. Integrative conceptual model and implementation conditions

The proposed synergistic model should be interpreted as a conceptual integration rather than an empirically established system-level effect. The current literature provides partial support for individual links within the model, while evidence for combined, season-long, team-level integration remains limited. To make the integrative logic explicit, Figure 1 summarizes how VR, biofeedback or neurofeedback, and mindfulness converge on empowerment-relevant mechanisms, and where AI can realistically operate as an implementation layer. In the model, VR is positioned as the primary context generator, providing representative exposure to decision constraints and pressure cues. Biofeedback is positioned as a regulation training component that supports arousal control and interoceptive skill acquisition through feedback-guided practice. Mindfulness is positioned as a component of cognitive–emotional regulation that supports attentional stability, acceptance, and rapid refocusing after distractions or errors. Synergy is expected when regulation scripts are consistent across modalities, for example, the same brief

breath–cue routine is rehearsed during biofeedback, embedded in VR pressure scenarios, and reinforced through mindfulness-based refocusing practice. AI is positioned as a decision-support and personalization layer that can adjust dose, timing, and task difficulty based on observable trends, while operating under governance safeguards that protect privacy, consent, autonomy, and minimize digital load.

Figure 1 illustrates a mechanism pathway in which (i) VR provides representative exposure and rehearsal under pressure, (ii) biofeedback supports arousal regulation and perceived control through feedback-guided practice, and (iii) mindfulness supports attentional stability, acceptance, and rapid refocusing. These mechanisms converge on performance stability and well-being outcomes. AI is presented as an implementation layer that supports personalization, scheduling, and trend-based monitoring under human oversight and within ethical safeguards to prevent erosion of autonomy, monitoring burden, and data misuse.

Practical implementation depends on feasibility constraints that vary by resource level and team context. Key requirements include protected time within the

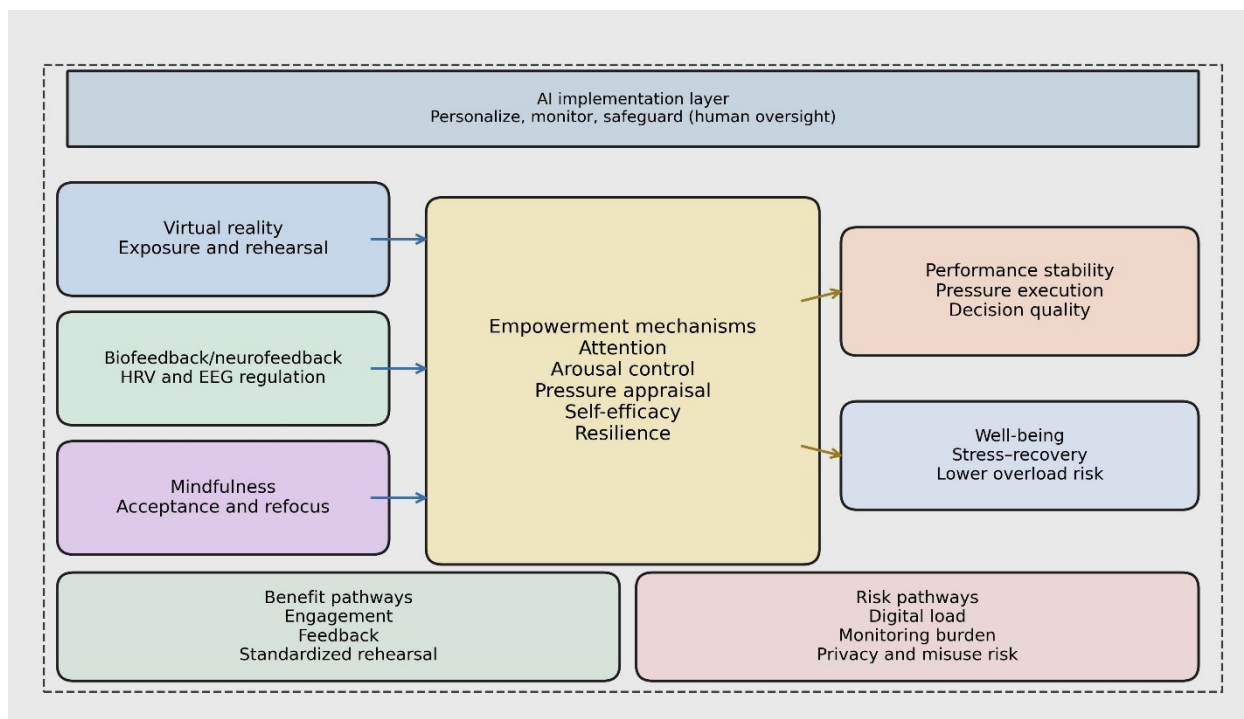


Figure 1. Integrative conceptual model of virtual reality, biofeedback or neurofeedback, and mindfulness, with AI as an implementation layer. Image created by the authors using AI.

Abbreviations: AI: Artificial intelligence; EEG: Electroencephalography; HRV: Heart rate variability.

Table 8. Integrative and artificial intelligence evidence table presenting study-level summaries with transfer indicators and qualitative evidence weight

Source	Type	Primary context	Integrated focus	Outcomes and endpoints	Transfer indicators	Key limitations and bias signals	Qualitative evidence weight
Wagner & Wiczorek ⁸⁶	Experimental study	Pressure performance paradigm	Virtual reality (VR) based mindfulness breathing with integrated biofeedback undergo depletion	Motor skill performance under pressure, regulation related outcomes	Transfer is task-based; competitive transfer not established	Laboratory paradigm; generalization to basketball match contexts uncertain; depends on sample and comparator details	Moderate to higher
Pratviel <i>et al.</i> ⁵⁷	Experimental comparison	Stress and anxiety context	Relaxing VR immersion versus heart rate variability (HRV) biofeedback	Stress and anxiety outcomes	Indirect for sport and basketball	Acute endpoints; non-sport setting; performance outcomes not primary	Moderate (acute regulation), indirect (basketball)
Blum <i>et al.</i> ⁵²	Development and pilot	General sample	VR respiratory biofeedback approach	Feasibility and physiological regulation outcomes	Indirect for sport	Pilot scope; limited external validity; transfer not tested	Lower to moderate
Wiczorek <i>et al.</i> ⁵⁸	Replication study	Health and psychology context	Mobile VR mindfulness breathing meditation with integrated biofeedback	Physiological and psychological health effects	Indirect for sport	Transfer to sport outcomes not tested; adherence context-dependent	Moderate (health outcomes), indirect (basketball)
Lu <i>et al.</i> ⁶⁶	Conference proceedings	Human-computer interaction and design context	Biofeedback based VR game for mindfulness practice	Engagement and mindfulness practice outcomes	Indirect for sport	Prototype evidence; limited methodological detail; replication needed	Lower
Tsai <i>et al.</i> ⁸⁵	Feasibility study	Basketball	VR based tactic training	Feasibility and task performance indicators	Mainly within system, competitive transfer not established	Feasibility emphasis: outcomes often proxy-based	Moderate (feasibility), indirect (transfer)
Tsai <i>et al.</i> ⁴²	Feasibility study	Basketball	Artificial intelligence and VR for decision training	Feasibility and decision task performance	Primarily within system	Limited ecological transfer testing; comparator and sample size determine inference	Moderate (feasibility), indirect (transfer)
Zamora <i>et al.</i> ⁵¹	Original empirical	Men's basketball	HRV plus accelerometry for workload control	Readiness and workload management signals	Monitoring, not an intervention transfer test	Observational applied monitoring; requires cautious inference	Moderate (monitoring relevance)

(cont'd...)

Table 8. (Continued)

Source	Type	Primary context	Integrated focus	Outcomes and endpoints	Transfer indicators	Key limitations and bias signals	Qualitative evidence weight
Petway <i>et al.</i> ³⁹	Systematic review	Basketball	Training load and match-play demands across competition levels	Demand profiles across levels	Indirect for psychological intervention transfer	Not an intervention efficacy source; informs scheduling constraints	Higher (context constraints), indirect (intervention effects)
Fuster <i>et al.</i> ⁹	Original empirical	Professional women's basketball	Cognitive load monitoring in competitive environments	Cognitive load indicators	Indirect for intervention efficacy	Measurement and interpretation limits; transfer to decisions depends on framework	Moderate
West <i>et al.</i> ⁴⁰	Critical discussion	Sport and exercise medicine	Big data benefits and risks	Governance and implementation risks	Not applicable	Not an efficacy study; informs ethics and caution	Moderate to higher (governance relevance)
Jimenez & Verhagen ⁶⁷	Conceptual critique	Athlete monitoring	Monitoring validity and injury prevention claims	Limits of current monitoring inference	Not applicable	Not efficacy evidence; strengthens interpretive caution	Moderate to higher (inferential caution)
Schack ⁸²	Conceptual review	Sport psychology technology	Key characteristics and applications of new technologies	Implementation framing	Not applicable	Not efficacy evidence; supports implementation logic	Moderate
Lew <i>et al.</i> ⁵³	Applied chapter	High performance settings	Technology integration in sport psychology workflows	Implementation considerations	Not applicable	Chapter level synthesis; context dependent	Moderate

microcycle, appropriate access to equipment, staff competence for delivery and interpretation, and a governance plan for monitoring data. Table 9 summarizes practical conditions, including time burden, cost tier, and expertise needs, to support realistic adoption beyond elite settings.

4. Critical appraisal and limitations

While the promise of VR, biofeedback, and mindfulness interventions is evident, the evidence base requires careful appraisal. Methodological and practical limitations constrain inference and highlight priorities for future research. Literature spans diverse designs, including small pilot studies without robust comparators, controlled trials, and quasi-experimental studies, qualitative and

mixed-methods research, feasibility and prototype work, and higher-level syntheses (systematic reviews and meta-analyses). This heterogeneity limits the feasibility of estimating a single overall effect size and complicates comparison across protocols that differ in dose, fidelity, delivery format, and outcomes. In VR research, interventions are often brief, and outcomes frequently rely on simulation-based or laboratory proxies. In mindfulness research, interventions vary widely in duration and content. In biofeedback and neurofeedback, protocols differ substantially in physiological targets and comparator conditions. As a consequence, interventions labelled under the same umbrella term (e.g., “VR training” or “mindfulness”) are not necessarily equivalent, which likely contributes to mixed findings.

Table 9. Practical conditions for implementation of the integrated model (time, costs, expertise)

Implementation element	Minimum viable implementation (resource-limited teams)	Moderate implementation (typical competitive programs)	Advanced implementation (elite and well-resourced programs)
Time commitment	10–20 min per week total, embedded as micro-practices within regular sessions	30–60 min per week total, divided across 2–4 short blocks	60–120 minutes per week total, including individualized modules
Virtual reality (VR) component	Optional, replaced by video-based decision scenarios and pressure drills	Short VR blocks 10–15 min, 1–2 times per week, representative scenarios	High-fidelity VR with adaptive scenarios, integrated into tactical training cycles
Biofeedback component	Basic breathing practice with simple heart-rate monitoring, minimal data retention	Heart rate variability (HRV) biofeedback blocks 5–10 minutes, 2–3 times per week, simple trend feedback	Validated HRV systems, optional neurofeedback for selected athletes, structured transfer sessions
Mindfulness component	3–5 min centering or refocusing scripts before or after practice	Brief weekly group session plus micro-practices embedded in routines	Structured program with acceptance and refocusing components and individualized support
Artificial intelligence layer	None required, rule-based scheduling by staff	Simple trend alerts and scheduling support from existing platforms, human-in-the-loop	Integrated dashboards and adaptive task scheduling, uncertainty-aware decision support, human oversight mandatory
Cost profile	Low, uses existing equipment and staff time	Moderate, consumer-grade VR and validated sensors where possible	High, custom or premium systems, data infrastructure, dedicated support
Required expertise	Coach training in script delivery, basic monitoring literacy	Sport psychologist designs scripts, coaches implement, performance staff interprets HRV trends	Interdisciplinary team including sport psychologist, performance scientist, medical staff, and data governance support
Adoption barriers	Cultural acceptance, limited staffing, equipment access	Scheduling within congested microcycles, staff training, governance clarity	Monitoring burden risk, over-reliance on dashboards, privacy and role-boundary complexity

4.1. Evidence quality, study design distribution, and implications for inference

Evidence quality was appraised in relation to study design type, comparator strength, outcome validity, and transfer testing, consistent with the qualitative evidence weight approach described in the Methods. Across modalities, the included literature can be grouped into four broad categories. First, systematic reviews and meta-analyses provide higher-level synthesis but remain constrained by heterogeneity and the quality of primary studies. Second, controlled and quasi-experimental studies offer more interpretable causal signals, yet are frequently limited by small sample sizes, short follow-up, and reliance on task-based outcomes. Third, feasibility and prototype studies, particularly in VR- and AI-enabled systems, primarily support claims about implementability rather than

competitive performance effects. Fourth, observational and monitoring studies inform workload and readiness management, but do not establish intervention efficacy and require cautious interpretation due to measurement validity constraints and governance dependence.⁸⁷

These design differences directly shape what can be claimed. For example, VR- and AI-enabled tactic or decision-training studies commonly provide feasibility data and near-transfer outcomes, whereas fewer studies demonstrate ecological transfer to competition-level performance. In biofeedback, HRV protocols offer comparatively strong support for arousal regulation and certain pressure-sensitive skills, whereas evidence for EEG neurofeedback is complicated by protocol heterogeneity, limited blinding, and variable rigor of comparators. In mindfulness, the evidence base includes both positive

and null findings, suggesting that dose, athlete context, and implementation timing are meaningful boundary conditions rather than noise. Overall, the evidence supports cautious, mechanism-based conclusions, but not uniform claims of robust, durable in-game benefits across modalities.

Primary studies often use small samples, sometimes drawn from single teams or homogeneous groups, which limits statistical power and generalizability. Null findings may reflect underpowered designs, while positive findings may not replicate at scale. In addition, convenience sampling is common, including collegiate or recreational participants. Elite professionals may respond differently due to ceiling effects and distinct stressors such as travel load, media scrutiny, and schedule congestion. Sex and gender representation remain uneven, and basketball-specific studies in professional women's settings are comparatively limited, restricting subgroup inference.

A recurrent limitation concerns outcomes and ecological validity. Many VR and neurofeedback studies rely on proxy measures (e.g., reaction time, simulated decision accuracy) rather than competition-level outcomes, such as validated in-game indicators, coach ratings, or season-level performance metrics. Transfer to real competition remains the central empirical gap. Studies that assess basketball-relevant tasks provide stronger inference, but broader claims about durable competitive impact require longer-term designs, multi-site trials, and outcomes anchored in real match contexts.

Future work would benefit from multimodal measurement that combines at least one performance endpoint, one construct-aligned psychological measure connected to empowerment mechanisms, and one physiological indicator of regulation or recovery. Timing and durability also require emphasis, as acute changes do not necessarily translate into maintained improvements, and longitudinal follow-up remains limited.

The evidence base is constrained by several recurring limitations that directly affect interpretability. First, sample sizes are frequently small, particularly in VR, biofeedback, and neurofeedback studies, which reduces statistical power, increases uncertainty around effect estimates, and limits generalizability beyond the specific team or cohort studied. Second, because basketball-specific studies remain relatively sparse for some modalities, evidence is often extrapolated from other sports. Although cross-sport transfer may be plausible when task demands are closely aligned, such as decision-making under time pressure, precision execution, or stress regulation during set plays, transferability is not guaranteed. Differences in perceptual-cue structure, pacing, contact, and contextual stressors

can alter both mechanism engagement and the ecological validity of outcomes. Third, there is a limited number of basketball-specific randomized controlled trials, especially for VR and EEG neurofeedback, and comparator conditions are often weak or inconsistent. As a result, conclusions should be framed as mechanism-informed and evidence-weighted rather than definitive, and future work should prioritize adequately powered basketball-specific randomized controlled trials with representative tasks, validated in-game outcomes, and longitudinal follow-up to establish durable transfer.

4.2. Ethical and implementation challenges in digitally mediated training ecosystems

Ethical and implementation challenges are integral to interpretation, particularly when interventions rely on wearables, immersive systems, or AI-enabled analytics. These technologies can generate sensitive psychophysiological and behavioral data, creating risks related to privacy, data security, access control, and secondary use. Responsible implementation requires informed consent, data minimization, transparent role boundaries regarding access to individual-level metrics, and explicit avoidance of punitive monitoring practices. Monitoring burden and digital load should be treated as potential harms, especially in high-demand schedules. When technologies are experienced as surveillance or external control, autonomy and trust may be undermined, adherence may decrease, and empowerment-related benefits may be attenuated. Ethical governance should therefore be treated as a boundary condition for both implementation feasibility and the credibility of empowerment claims.

These considerations are particularly relevant to AI. Much of the current evidence on AI-related sport is feasibility-oriented or conceptual. Accordingly, AI is best interpreted as a decision-support and implementation layer that may facilitate personalization, scheduling, and trend monitoring under human oversight, rather than as an autonomous system that directly and instantly alters emotional or performance states. Claims about real-time state adaptation should be limited to contexts where empirical evidence supports such inferences; otherwise, they should be framed as future directions requiring validation.

4.3. Subjectivity risk in narrative synthesis and mitigation steps

Narrative synthesis carries an inherent risk of subjectivity in study selection and interpretation because it does not rely on a single quantitative aggregation pipeline. Several steps were taken to reduce bias and increase transparency.

Titles and abstracts were screened independently by two reviewers; disagreements were resolved by discussion, and an a priori extraction matrix aligned with the guiding questions structured coding across protocol features, mechanisms, outcomes, ecological transfer, and ethical considerations. A qualitative trustworthiness appraisal was embedded, and findings were interpreted in proportion to the weight of evidence, prioritizing convergent patterns supported by controlled designs or consistent independent evidence, while explicitly qualifying conclusions when evidence was limited by small samples, weak comparators, proxy outcomes, or lack of follow-up. Study-level summaries were consolidated into structured tables to reduce the risk that narrative emphasis could inadvertently overweight weaker evidence.

Despite these safeguards, selection effects remain possible, including publication bias, database coverage limitations, and heterogeneity in terminology and outcomes that may reduce retrievability. Conclusions are therefore presented as mechanism-informed and evidence-weighted rather than definitive, with several implications framed as priorities for future research rather than established effects.

5. Practical implications for coaches, sport psychologists, and medical staff

Translating the evidence into practice requires moving from isolated tools to a mechanism-aligned program that is feasible within the constraints of real basketball training. Practical implementation is strongest when interventions are embedded within weekly training rhythms, tailored to athletes' roles and stress profiles, and governed by clear ethical and data-access rules so that monitoring supports autonomy rather than surveillance.⁴⁰ The recommendations below emphasize underutilized practices, concrete application scenarios, and role clarity across an interdisciplinary staff structure.

5.1. Implementation principles that reduce failure and increase transfer

The following principles outline practical considerations for effective implementation:

- (i) Train mechanisms, not technologies. Each session should specify the target construct, for example, attentional control, cognitive appraisal under pressure, arousal regulation, acceptance and refocusing, self-efficacy, or recovery after errors. VR, biofeedback, and mindfulness should then be selected as delivery modes that best train that construct within representative constraints.
- (ii) Prioritize transfer design over novelty. Near-transfer

gains within an app or simulation have limited value unless athletes can reproduce the skill during competition. Transfer is strengthened by linking training to identifiable game moments, such as free throws, timeouts, late clock decisions, foul trouble, and post-error recovery routines, and by rehearsing the same regulation script across environments.

- (iii) Use microdosing and timing, not maximum volume. Underutilized high-impact practices include short, repeated regulation exposures that are placed immediately before or after realistic stressors. This approach also reduces the burden during periods of congestion.
- (iv) Use monitoring as education and self-calibration, not as evaluation. Readiness indicators can support planning, but their value depends on interpretation and governance. Transparent explanation, athlete access to their own trends, and role-based data access reduce mistrust and monitoring burden.⁵¹

5.2. Role division and interdisciplinary workflow

The most effective delivery model assigns complementary tasks to each discipline while avoiding duplicated effort and unclear authority. A practical workflow is presented in [Table 10](#).

5.3. Concrete intervention scenarios

The following scenarios illustrate how the modalities can be combined without overloading athletes, and how each professional group contributes.

- (a) Scenario A. Competition-related stress regulation for free throws

Objective: stabilize execution under pressure by training arousal regulation, attentional control, and appraisal.

Set up: 8 to 12 minutes, 2 to 3 times per week for 4 to 6 weeks, embedded in practice.

- Sport psychologist role: designs a two-step script, one breath at resonance pace and one attentional cue, defines appraisal language, challenge framing rather than threat framing.
- Coach role: runs a pressured free-throw drill with realistic constraints, time pressure, audience noise simulation, and a consequence structure that is instructional rather than punitive.
- Medical and performance role: uses HRV trends as a readiness context, not a selection tool, flags unusually low recovery trends for supportive action, not discipline.
- Success criteria: reduced performance variability across pressured repetitions, faster recovery after

Table 10. Role delineation for an integrated mental training program

Task domain	Sport psychologists and mental performance consultants	Coaches and skill staff	Medical and performance staff
Mechanism targets and scripts	Define target constructs per athlete role, design brief regulation scripts, for example pre-free throw routine, post-error reset, pressure appraisal cues	Embed scripts into drills and competitive simulations, reinforce adherence during practice	Ensure scripts align with recovery and health constraints, screen for contraindications
Virtual reality (VR) scenario selection and design	Specify psychological demands, for example attentional distraction, time pressure, evaluative cues, define success criteria beyond outcome	Implement VR as short adjunct blocks, integrate with tactical teaching and decision drills	Monitor tolerability, cybersickness risk, and return to play constraints
Heart rate variability and biofeedback implementation	Train athletes in breathing and refocusing routines, define when to apply in game, support autonomy-supportive framing	Provide short, structured windows, for example pre practice, recovery blocks, timeout simulations	Validate device choices, monitor data quality, interpret trends conservatively, maintain confidentiality
Mindfulness and acceptance training	Deliver structured sessions, emphasize acceptance and refocusing under error and criticism, adapt language to team culture	Reinforce micro practices in routine moments, warmups and cool downs	Align with recovery and sleep goals, identify when mental fatigue and overload are present
Data governance and ethics	Ensure consent language is clear, prevent coercive use, support athlete agency	Avoid public ranking and punitive interpretation, focus on learning goals	Implement access control, data minimization, secure storage, define clinical escalation pathways

misses, and improved perceived control.

This scenario is underutilized because teams often train free throws technically, but do not standardize the regulation script that precedes execution. Evidence that HRV biofeedback can support pressure-sensitive performance tasks supports this rationale.

(b) Scenario B. Virtual reality decision training with embedded attention control

Objective: improve cue utilization and decision speed under time pressure while protecting autonomy. Set up: 10 to 15 minutes, 1 to 2 times per week, early in the week when cognitive freshness is higher.

- A sport psychologist's role: defines the attentional target, for example, scan order or key defender cues, and a reset routine after an error.
- Coach role: selects scenarios that match the team's tactical system, then links VR decisions to a short on-court repetition immediately after VR to strengthen transfer.
- Medical and performance role: monitors tolerability and fatigue, avoids placing VR decision blocks after heavy conditioning or travel.

Feasibility work supports that VR-based tactic and decision training systems can be implemented, but transfer claims should remain conservative unless competition outcomes are tested.

(c) Scenario C. Recovery day regulation block after high load periods

Objective: reduce stress load and support recovery by combining brief biofeedback and mindfulness.

Set up: 12 to 20 min, scheduled after games or high-demand training days.

- Sport psychologist role: delivers a short acceptance and refocusing practice tailored to post-game rumination and criticism exposure.
- Medical and performance role: uses HRV and sleep indicators to decide whether the day's emphasis is down regulation, sleep preparation, or light activation, and explains the decision to athletes to reinforce agency.
- Coach role: reinforces that recovery is performance work, avoids framing as optional or as weakness.

(d) Scenario D. Feedback interface design and data

governance

Objective: ensure monitoring supports empowerment and does not become surveillance.
Set up: implement a minimal dashboard and access policy.

Design recommendations:

- Use trend-based displays, not single-day scores, and avoid public rankings.
- Provide athletes with their own data and meaningful explanations, not only staff access.
- Use role-based access, medical staff see individual-level health indicators, coaches see aggregated readiness trends unless athletes opt in to share individual data.
- Document consent, data retention limits, and escalation rules for health concerns.

This is an underutilized practice because teams often adopt devices before defining governance, which increases mistrust and monitoring burden.

5.4. Accessibility and adoption in non-elite settings

Smaller teams and non-elite athletes often face constraints, including cost, limited staff expertise, cultural acceptance, and inadequate infrastructure. Practical pathways include:

- (a) Minimum viable program, low-cost tier
 - o Replace VR with video-based decision scenarios and structured pressure drills.
 - o Use basic HR monitors for simple breathing practice without continuous data collection.
 - o Use brief coach-led mindfulness scripts developed by a sport psychologist, delivered in 3-to-5-min blocks.
 - o Focus on one mechanism per month, rather than multiple simultaneous tools.
- (b) Incremental technology adoption
 - o Begin with one team champion and one pilot cohort, then scale after evidence of athlete acceptability.
 - o Provide staff training on interpretation limits and avoid overclaiming injury prevention from monitoring signals.
- (c) Cultural acceptance strategies
 - o Use sport-specific language, performance stability, and recovery rather than generic wellness framing.
 - o Normalize psychological training by embedding it in routine practice rather than isolating it as a separate activity.

5.5. Summary of practical contribution

A credible applied program requires mechanism

alignment, transfer design, and governance safeguards. Underutilized practices that can add immediate value include standardized pressure-regulation scripts for free throws, post-error reset routines, and minimal, autonomy-supportive dashboards that reduce monitoring burden. Interdisciplinary collaboration should be operationalized through clear role division, with sport psychologists designing scripts and construct targets, coaches embedding them in representative drills and VR environments, and medical and performance staff ensuring data validity, recovery timing, and ethical governance.

6. Conclusion and future directions

This narrative review examined how virtual reality, biofeedback or neurofeedback, and MBIs may contribute to psychological empowerment and athlete well-being in basketball, and how AI may realistically function as an implementation layer within a digitally mediated performance ecology. Across modalities, the most defensible conclusions are mechanism-informed and evidence-weighted. Promising signals are observed for specific self-regulation processes and pressure-relevant tasks, while clear limits remain in heterogeneity, ecological transfer, feasibility, and governance.

6.1. Guiding question 1: mechanisms and constructs supported by current evidence

Across the three pillars, the empowerment mechanisms most consistently implicated are attentional control and cue utilization, arousal regulation and interoceptive awareness, cognitive appraisal under pressure, acceptance and rapid refocusing, self-efficacy as perceived control, and resilience as recovery after errors and stress exposure.

Virtual reality interventions most plausibly target attentional control and cue utilization through representative perceptual-cognitive rehearsal, and may influence cognitive appraisal by reducing novelty and threat-based interpretations when pressure cues are repeatedly encountered. When VR scenarios are representative and interactive, repeated successful execution can plausibly support self-efficacy and perceived control, although these constructs are often inferred rather than measured directly in basketball-specific work.

Biofeedback, particularly HRV biofeedback, most directly targets arousal regulation and interoceptive awareness through resonance breathing and real-time feedback. This pathway is conceptually aligned with perceived control over stress responses and may support pressure-sensitive performance stability when athletes learn to implement the skill in realistic contexts. EEG neurofeedback is conceptually aligned with attentional

stability and arousal control, but inference is constrained by protocol heterogeneity and limited basketball-specific transfer outcomes.

Mindfulness-based interventions most plausibly operate through attentional control and meta-awareness, acceptance and psychological flexibility, and appraisal processes that reduce rumination and self-evaluative threat under pressure. Some basketball-relevant studies indicate performance benefits in pressure-sensitive skills, while null findings in ultra-brief protocols suggest meaningful boundary conditions and indicate that skill acquisition mechanisms may require sufficient dose and contextual fit.

Overall, the evidence supports a coherent mechanism account, but direct measurement of empowerment constructs remains inconsistent. The strongest interpretations are those in which mechanisms are explicitly operationalized and linked to basketball-relevant tasks rather than inferred from proxy outcomes alone.

6.2. Guiding question 2: protocol efficacy, limits, and boundary conditions

Protocol efficacy appears contingent on dose, fidelity, task representativeness, comparator strength, and whether ecological transfer is assessed.

For VR, the most promising protocols are interactive and representative of basketball decision constraints, including time pressure and cue-rich scenes. However, the evidence base is constrained by short interventions, small sample sizes, and frequent reliance on near-transfer outcomes within simulation environments. Standardized reporting of fidelity, interactivity, tolerability, and transfer assessment remains a priority (Table 10).

For HRV biofeedback, multi-session protocols that teach resonance breathing and explicitly connect the skill to competition-relevant moments are the most plausible candidates for improving pressure-sensitive performance stability. Device heterogeneity and measurement validity remain central constraints, particularly when consumer wearables are used without validation. Monitoring studies can inform readiness management, but monitoring is not equivalent to intervention efficacy, and interpretation remains governance-dependent.

For mindfulness, protocols that extend beyond ultra-brief exposures and embed practice into routines appear more likely to influence performance and stress regulation. Mixed findings indicate that dose, athlete level, timing, and adherence are meaningful boundary conditions. Well-being outcomes are often more variable than performance-related psychological skills, and broader mental health effects should be framed cautiously unless the outcome

targets and sampling strategy support such inferences.

For multimodal interventions, early experimental evidence suggests that combining VR-based exposure with breathing or mindfulness practice and physiological feedback can preserve performance under fatigue and pressure-like constraints. Comparative findings also suggest that different modalities can converge on similar acute down-regulation endpoints, which may be practically useful for preference-matched delivery. Nonetheless, the dominant limitation across modalities remains ecological transfer. Sustained effects across a season and improvements in validated in-game indicators are rarely demonstrated.

6.3. Guiding question 3: responsible artificial intelligence integration within a coherent framework

Artificial intelligence-enabled systems are most defensible as an implementation and decision-support layer rather than as an autonomous agent that directly alters emotional or performance states. The most realistic contributions include personalization of dose and timing based on readiness and workload signals, adaptive scheduling of regulation modules during periods of congestion, and trend-based dashboards that support human oversight. Evidence supporting AI in basketball contexts is largely feasibility-oriented and should be interpreted as task-level implementation signals rather than proof of competition-level impact.

Responsible integration requires governance safeguards as boundary conditions for empowerment rather than optional additions. Privacy, informed consent, data minimization, role-based access, and explicit avoidance of punitive monitoring are necessary to prevent erosion of autonomy and disruption of trust. Monitoring burden and digital load should be treated as potential harms, and systems should be designed to support athletic agency, transparency, and interpretability. Within this framework, AI is positioned as a tool that can support structured implementation while protecting autonomy and minimizing unintended cyber-related stressors.

6.4. Future research agenda

Future work should shift from feasibility and proxy outcomes toward ecologically valid designs that test mechanisms, boundary conditions, and durable transfer.

Study designs should prioritize multi-site, adequately powered trials with active comparator conditions, longitudinal follow-up, and preregistered hypotheses where feasible. Longitudinal mixed-method designs are recommended to combine objective performance

indicators and physiological endpoints with qualitative process data on adherence, acceptability, perceived empowerment, and trust. Pragmatic trials embedded within competitive seasons are needed to test whether effects generalize under travel, congestion, media scrutiny, and real competitive uncertainty. Given the relevance of cognitive depletion, future studies should incorporate validated measures of mental fatigue or manipulations and evaluate whether interventions preserve decision quality and technical execution under realistic load.

Target populations should expand beyond collegiate male samples. Priority groups include professional women's teams, youth development pathways, and adaptive sports athletes, including wheelchair basketball, where stress regulation pathways, accessibility needs, and implementation constraints may differ. Research should also address resource-limited settings by testing minimum viable intervention packages and cost-effective delivery models that smaller clubs can adopt.^{88,89}

Theoretical models should be operationalized rather than referenced implicitly. Mechanism testing should include direct measures of attentional control, appraisal under pressure, self-efficacy, psychological flexibility, and resilience processes, alongside objective performance endpoints and ecologically valid transfer indicators. Dose-response analysis and fidelity reporting should become standard to clarify why effects appear in some contexts and not others.

Artificial intelligence research should prioritize human-in-the-loop evaluation rather than speculative claims. Future studies should test decision-support systems in controlled field contexts, comparing AI-informed scheduling or adaptive VR difficulty against transparent rule-based schedules. Modelling uncertainty should be reported, and governance mechanisms should be evaluated empirically, including their impacts on trust, monitoring burden, perceptions of autonomy, and the effectiveness of safeguards in preventing misuse.

In summary, the evidence supports the plausibility of an integrated, mechanism-aligned program in which VR provides representative exposure and rehearsal, biofeedback supports physiological self-regulation, and mindfulness supports attentional stability and acceptance-based refocusing. The evidence base remains constrained by heterogeneity and limited ecological transfer, while AI is most defensible as a decision-support layer operating within robust ethical governance. Future research should therefore prioritize mechanism testing, ecologically valid outcomes, inclusive populations, and implementation models that are both effective and accessible.

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Availability of data

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Further disclosure

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